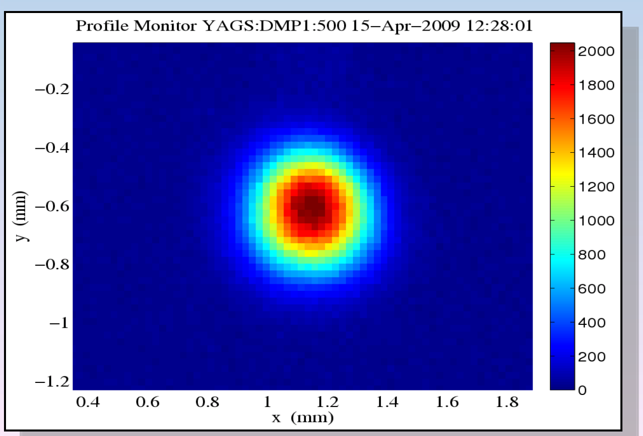
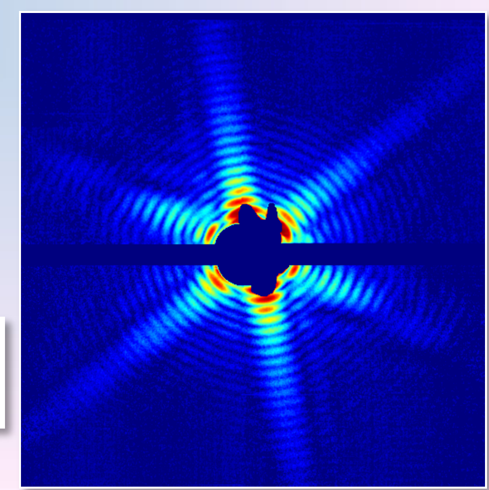
Technical Challenges in the LCLS, Commissioning and Upgrades

Zhirong Huang for the LCLS team



LCLS

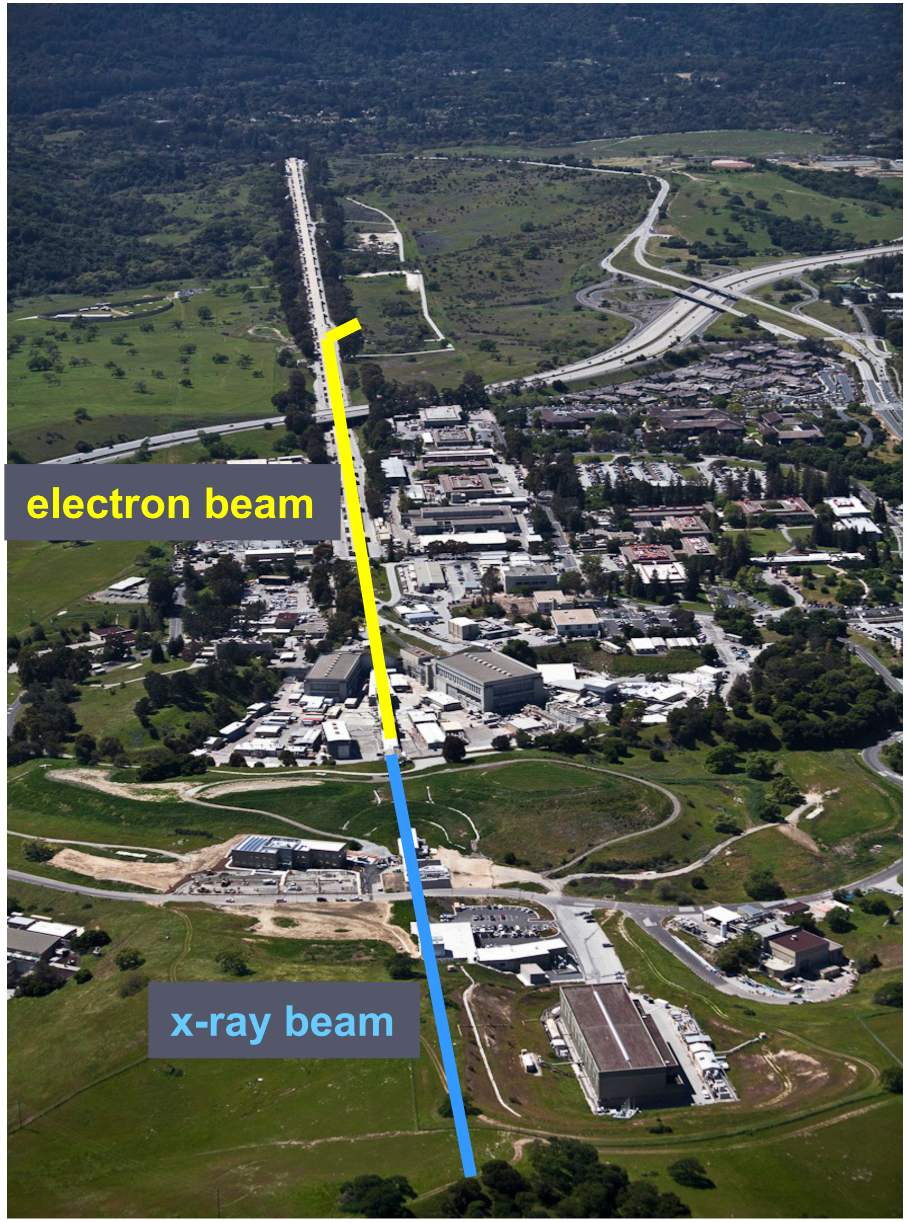
SLAC NATIONAL ACCELERATOR LABORATORY



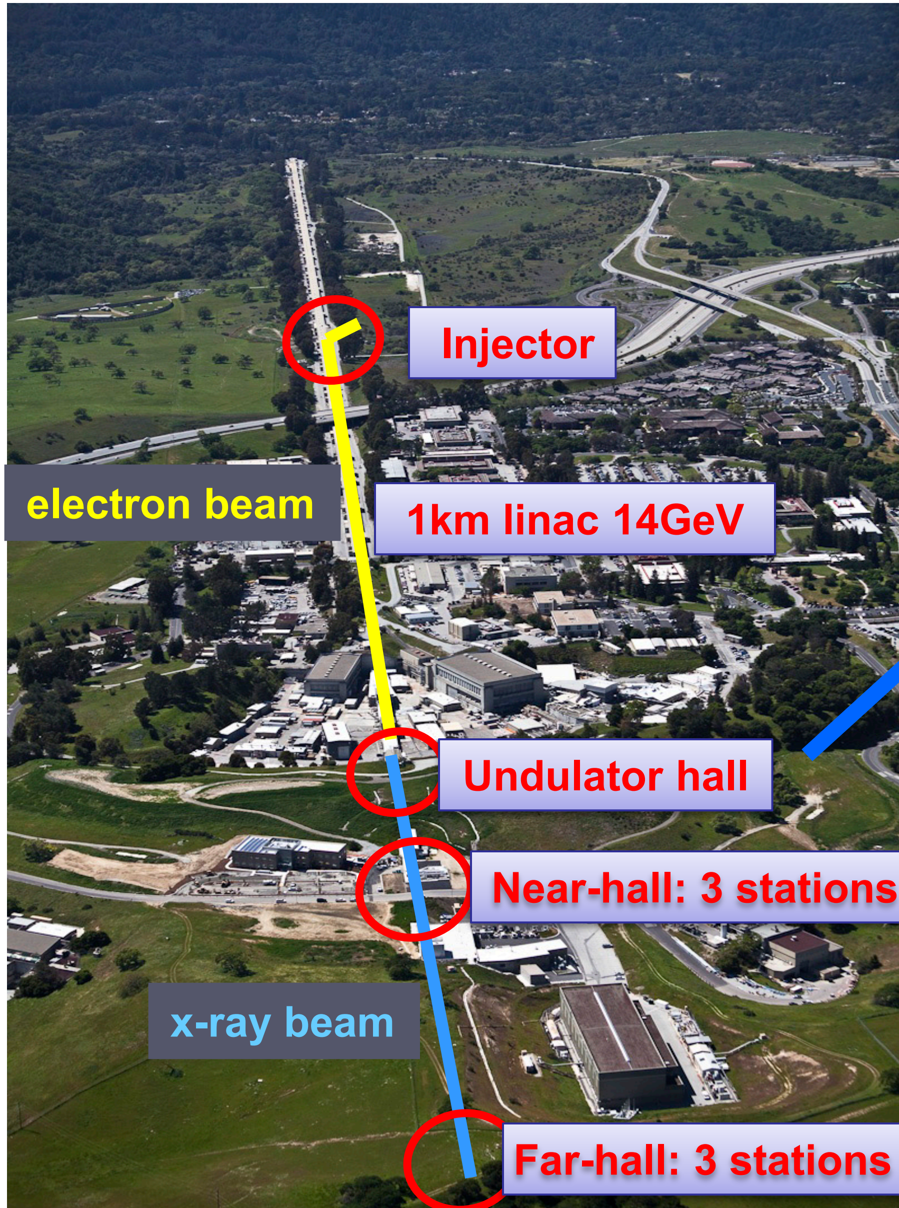
Outline

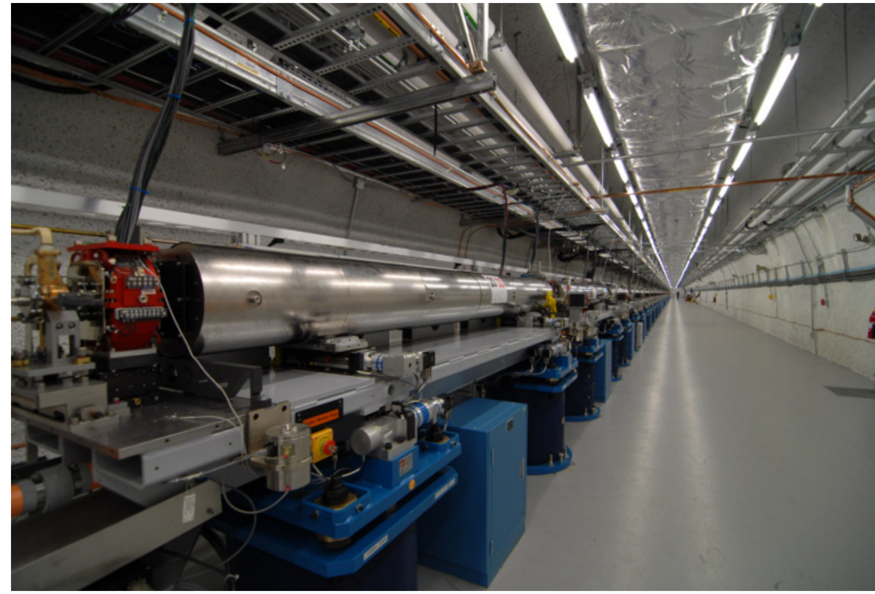
- Commissioning highlights
- Operation and user experience
- Near term upgrades
- LCLS-II and FEL R&D

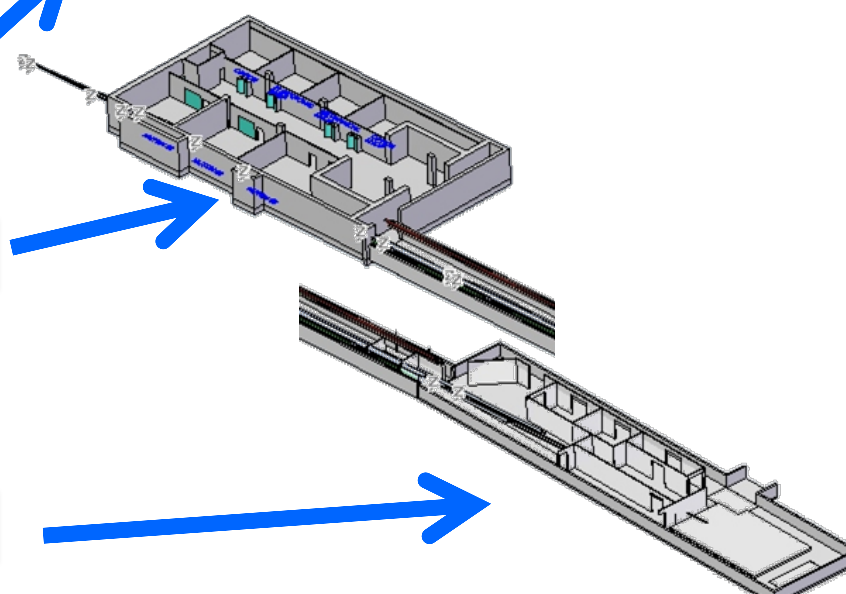
LCLS facilities overview



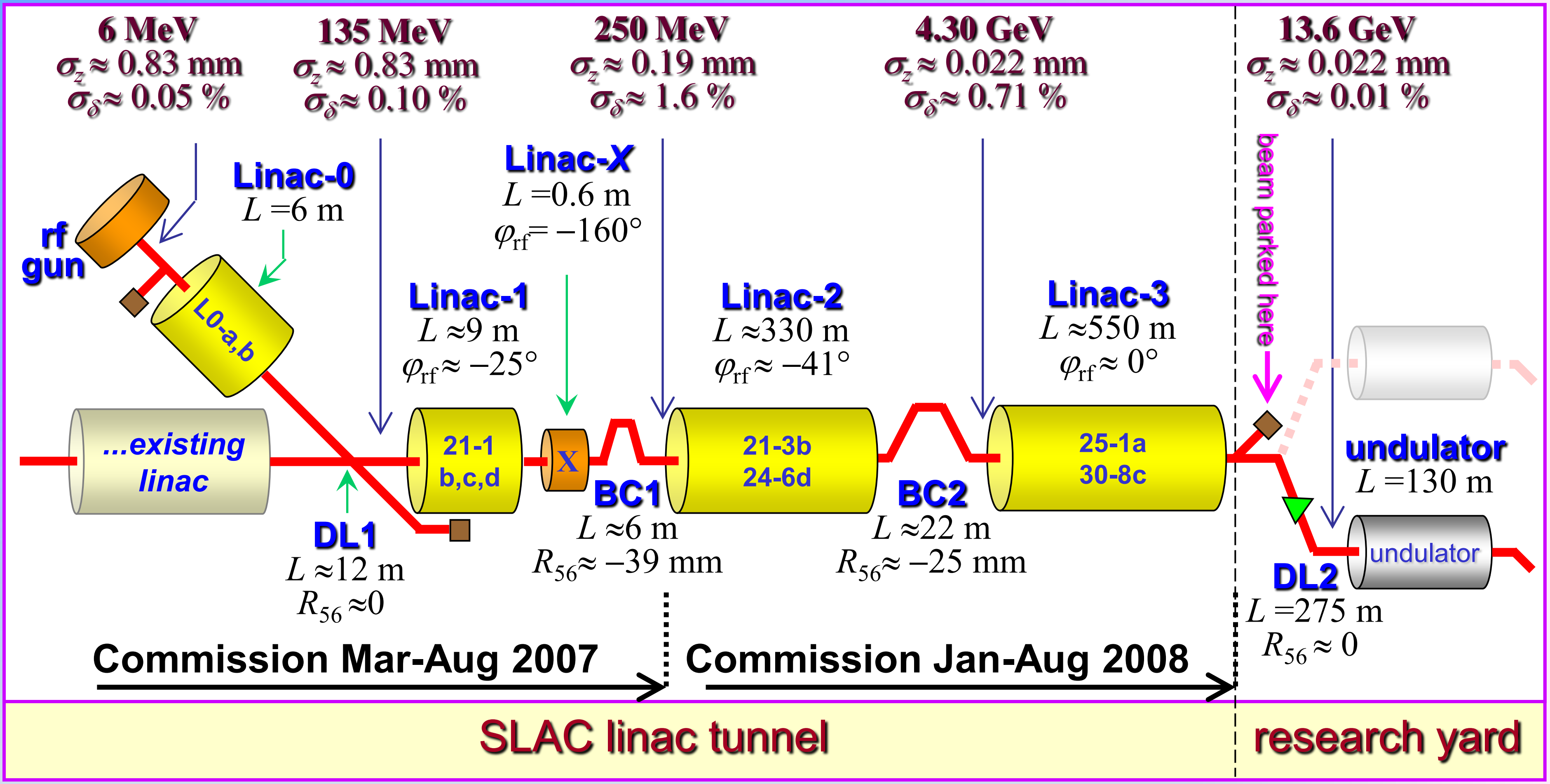
LCLS facilities overview







2.5 years of LCLS commissioning ends Oct. 2009



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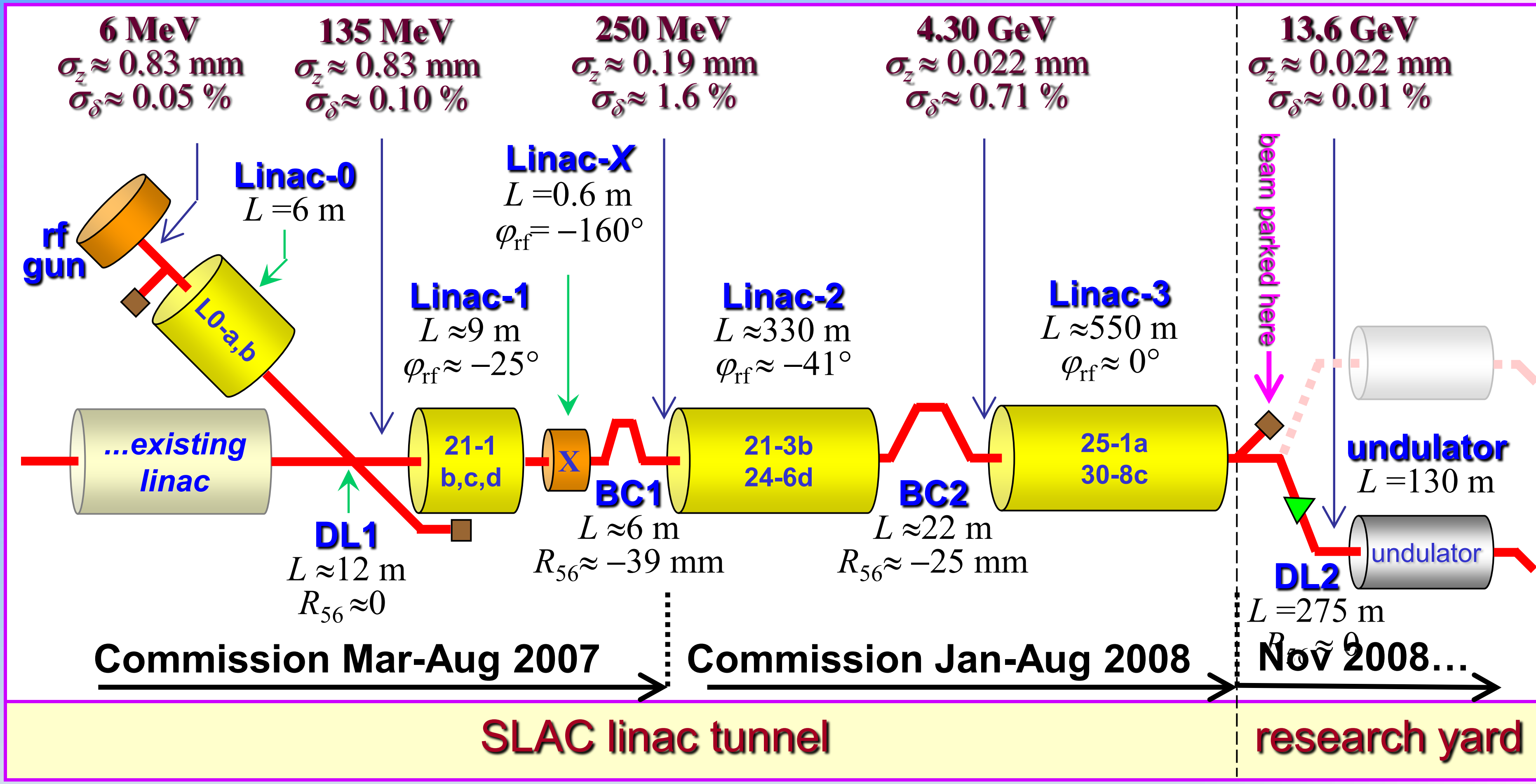


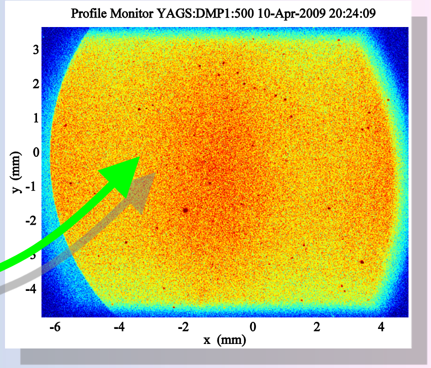
- Generation of low emittance beam
- Preservation of 6D brightness in accelerator/compressor
- Undulator tolerance and trajectory control

Don't underestimate 40+ years SLAC linac experience

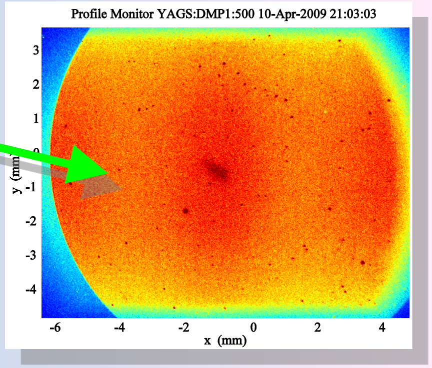
First Lasing (April 10, 2009)

- Reduce peak current to 500 A (normally 3000 A)

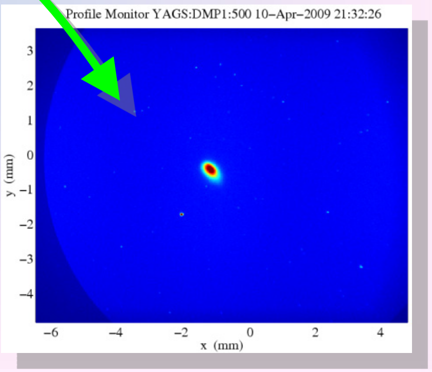
- Insert one undulator magnet (3.4 m) at a time. Correct orbit, check field integrals, & spontaneous radiation



- After 10 undulators inserted, we begin to see a smaller spot at center of screen (still 500 A)



- So we insert 12 undulators and then slowly raise the peak current back to 3000 A…



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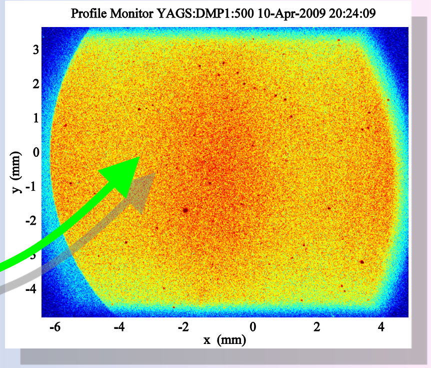

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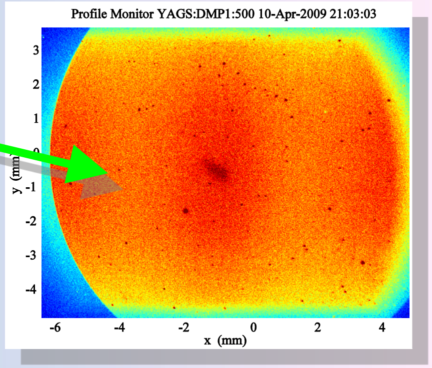

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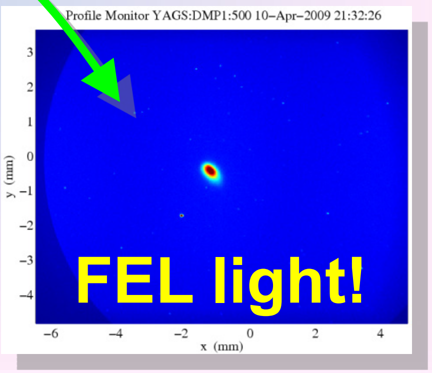
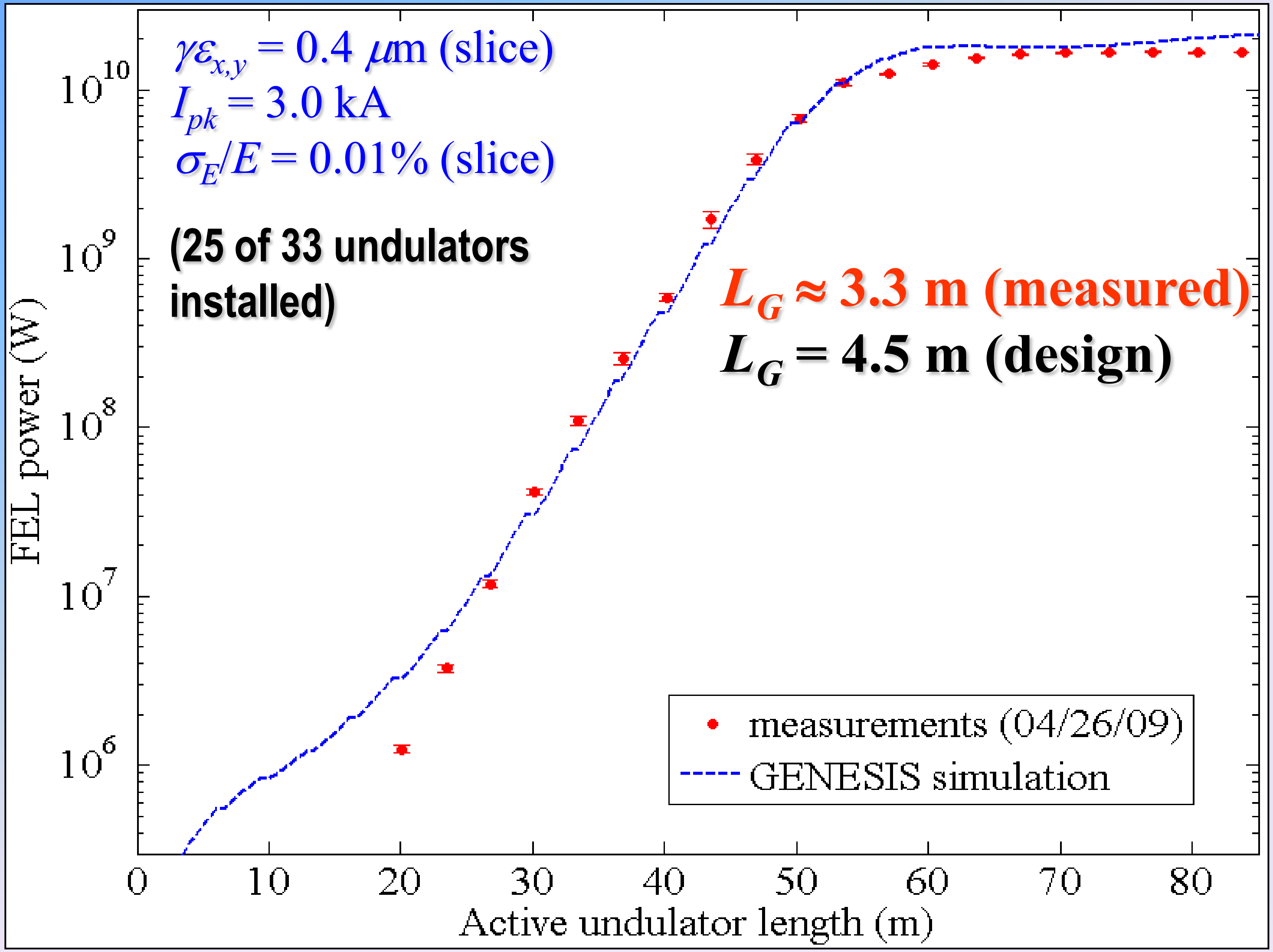


FEL saturation 1.5 Å

- 1.5 Å FEL saturation observed: **April 14, 2009**



P. Emma et al., PAC2009 & Nature Photonics 2010

LCLS Achievements

- Exceptional e^{-} beam quality from RF gun ($\gamma\varepsilon_{x,y} \approx \mathbf{0.4}$ μm)
- Pulse length *easily* adjustable for users (**60 - 500** fs FWHM)
- Low-charge mode (20 pC) allows <**10** fs pulses (~0.15 mJ)
- Wider photon energy range: **480 - 10000** eV (design was: 830 - 8300 eV)
- Peak FEL power >**70** GW (10 GW in CDR)
- Pulse energy up to **4** mJ (2 mJ in CDR)
- **96.7%** accelerator availability, **94.8%** photon availability
- **120 fs** pump probe synchronization has been achieved*

** **With cross-correlator and post-processing, see***
WEOBS2 *(Synchronization), J. Byrd*
THP168 *(FEL Beam Stability in the LCLS), F.-J. Decker*
MOP286 *(LCLS timing stability), M. Petree*

Outline

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SLAC/LCLS Main Control Center (MCC)

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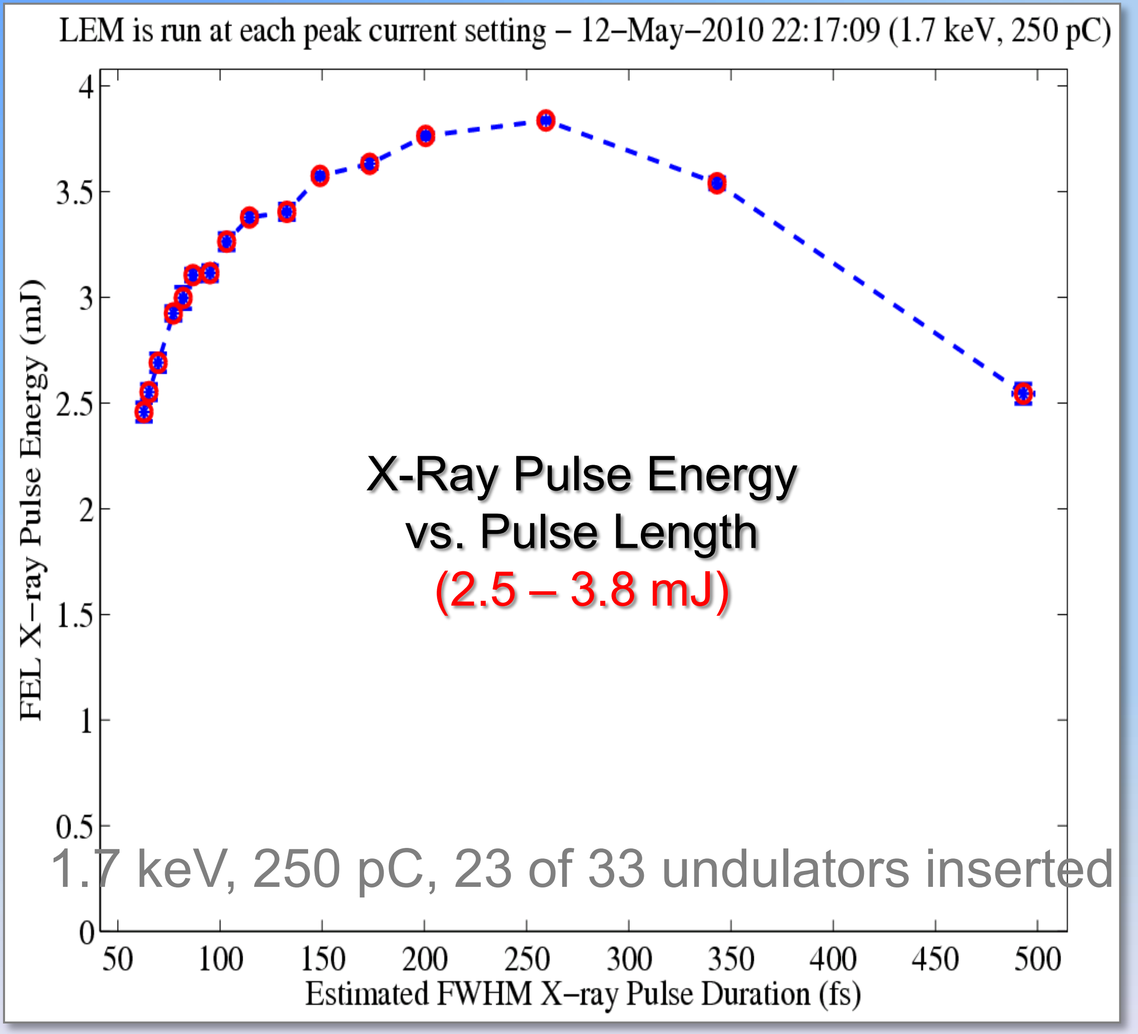
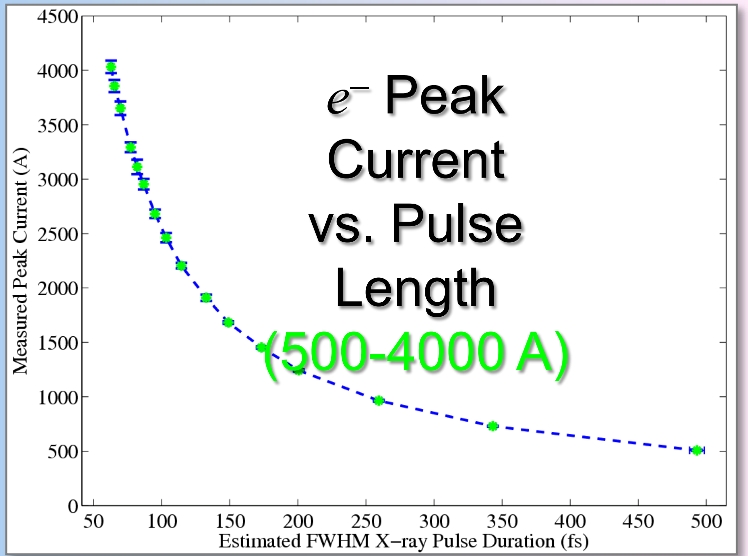
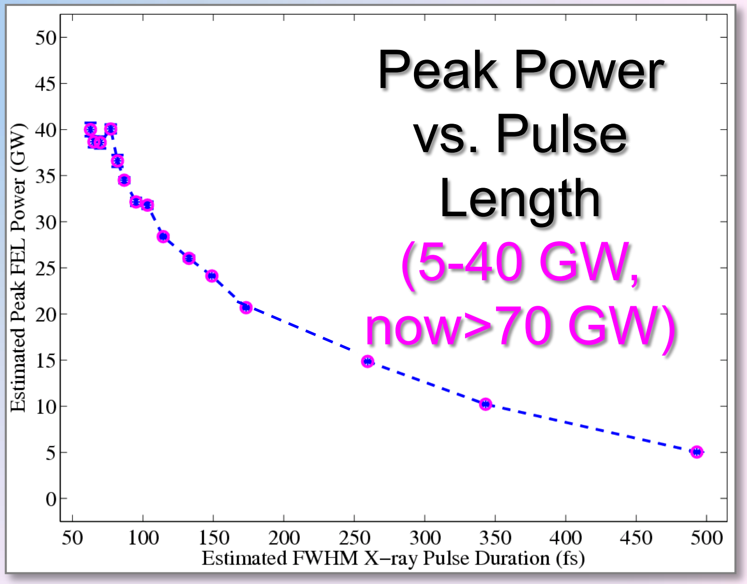
Pulse Length Easily Adjusted (500-60 fs)*





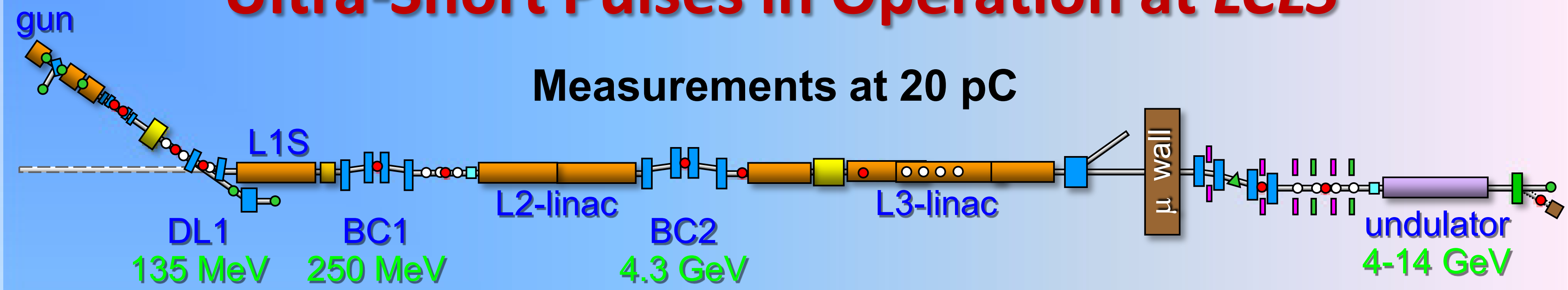


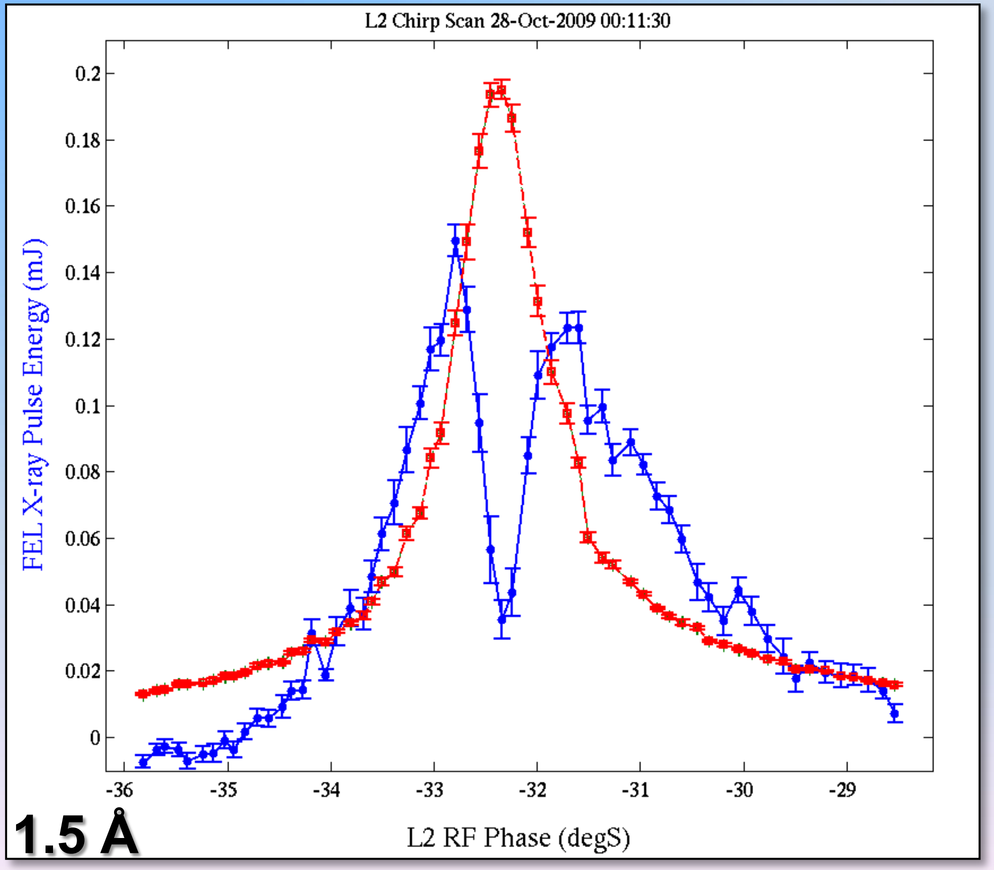
e^- bunch length is quickly adjustable (<1 min) from 60 to 500 fs (hard x-rays: 60 to 100 fs)

* for soft x-rays (0.5-2 keV)

Ultra-Short Pulses in Operation at *LCLS*

Measurements at 20 pC





$\Delta\varphi$

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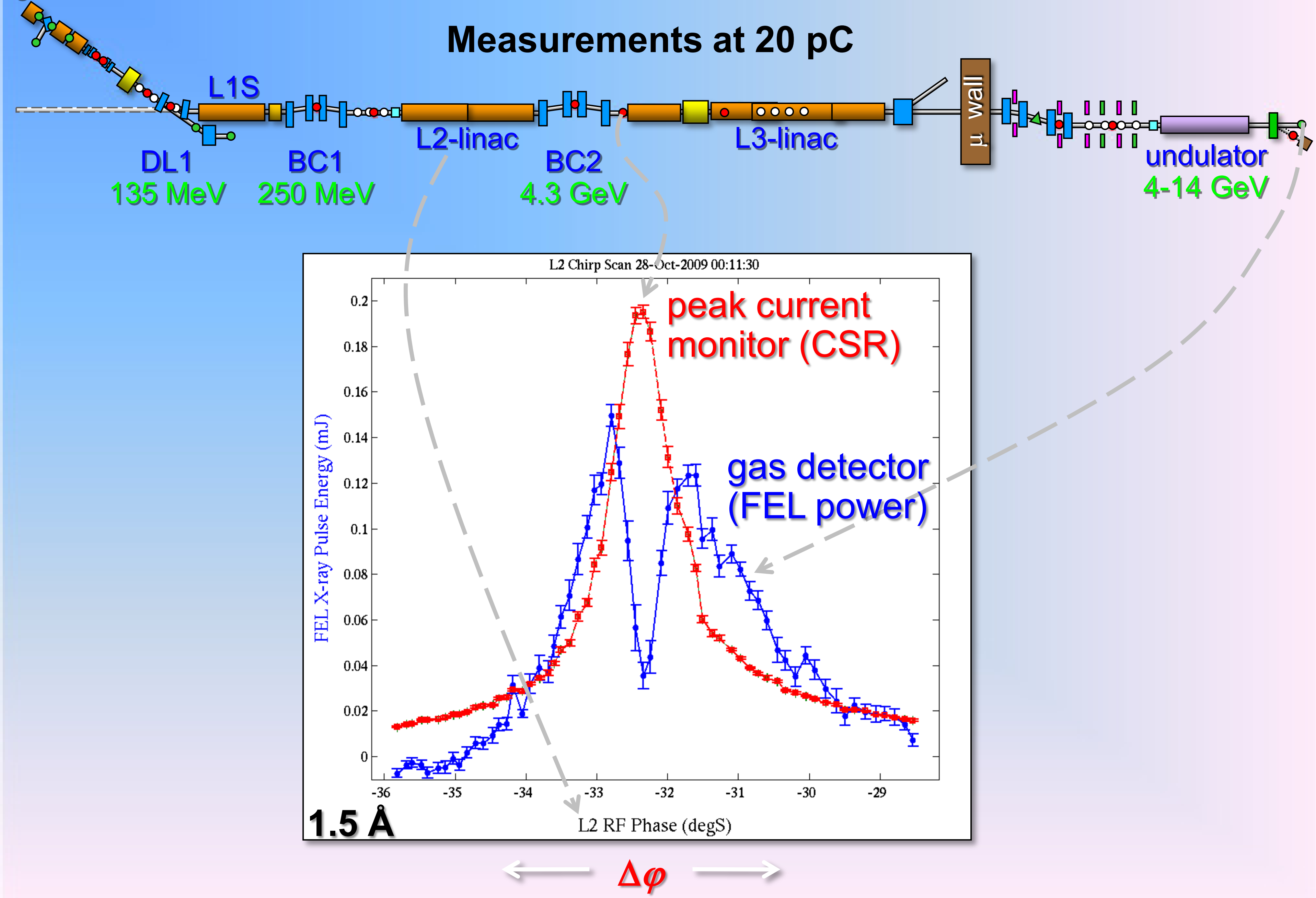

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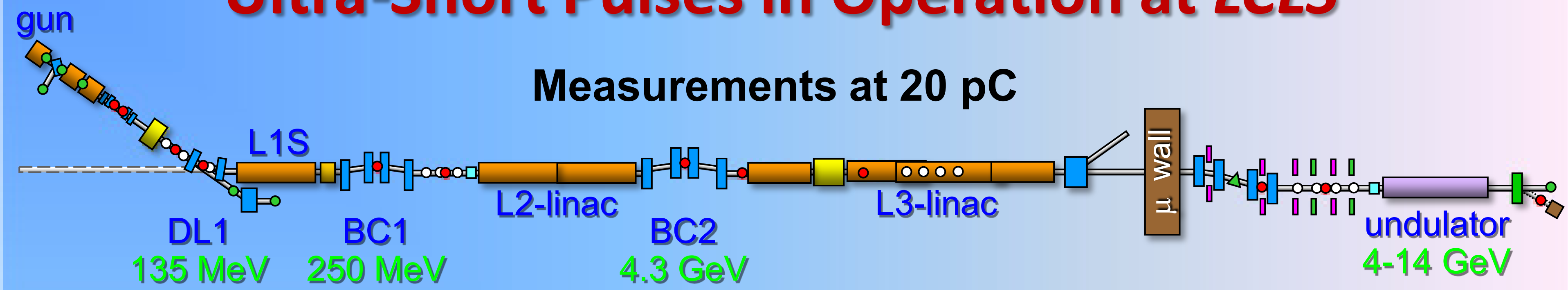
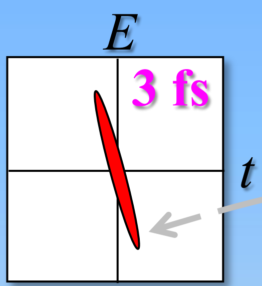
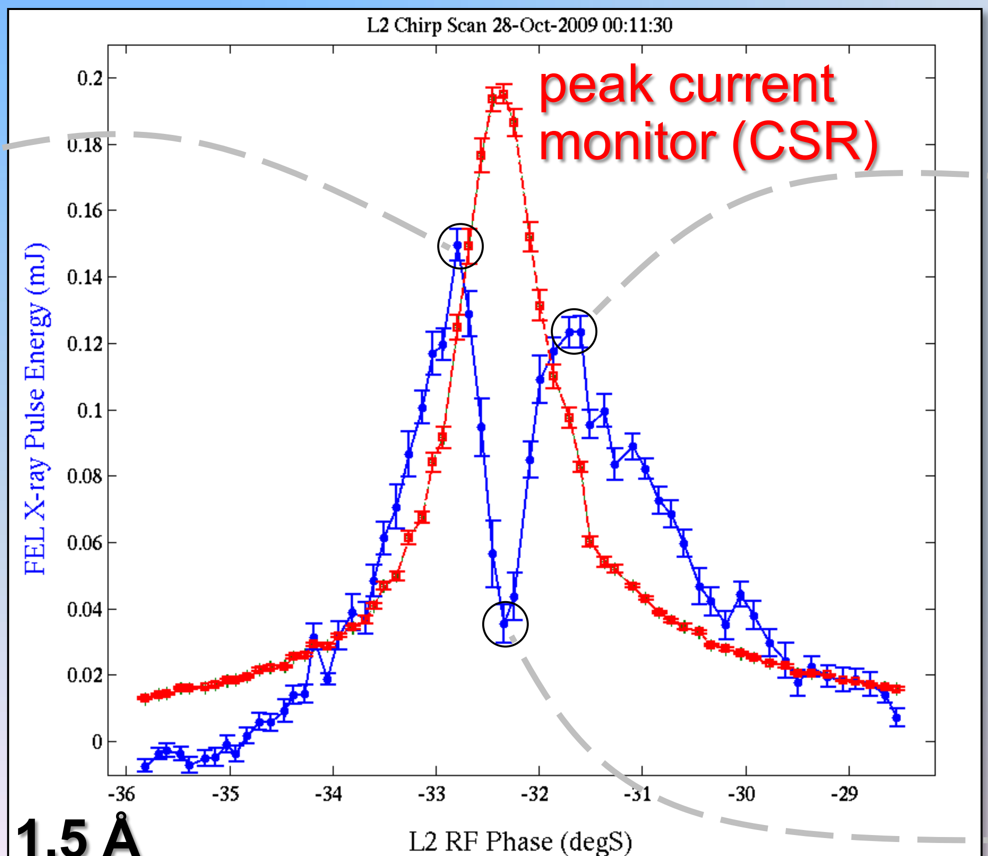
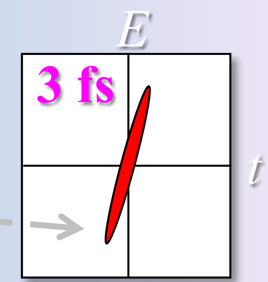




over-compressed
$\Delta\varphi = -0.5^{o}$

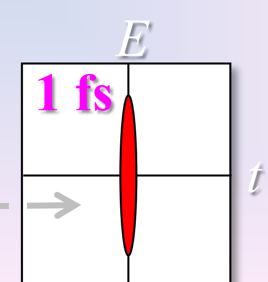


$\Delta\varphi$



under-compressed
$\Delta\varphi = +0.6^{o}$

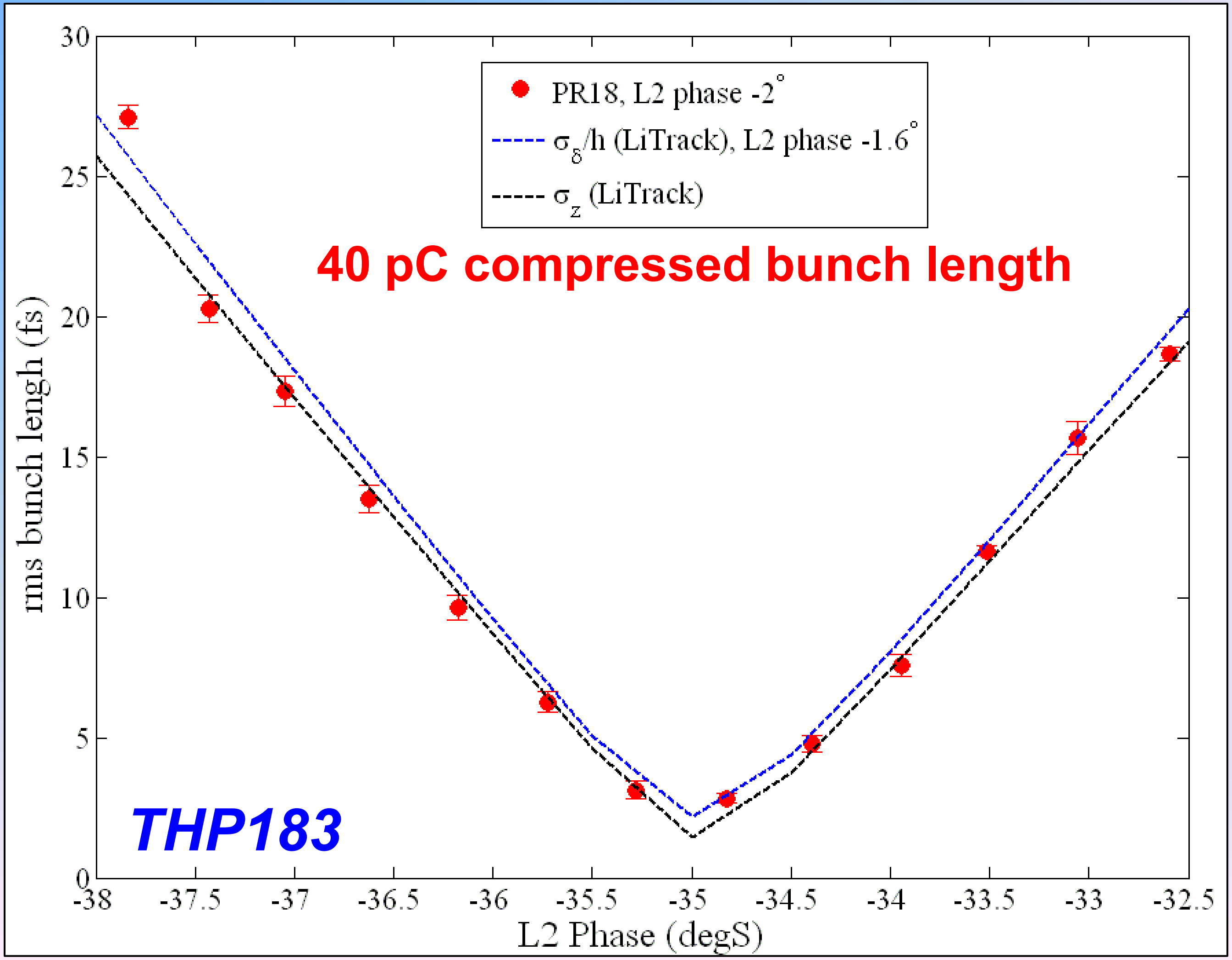
fully compressed



X-ray pulse duration is <10 fs at 20 pC (not measured)

Ultra-short bunch length measurement

- Transverse deflector lacks resolution to measure ultra-short low charge bunch (< 10 fs)
- A technique is developed to map time to energy, which can be measured with a high-resolution spectrometer (**~1 fs** resolution)



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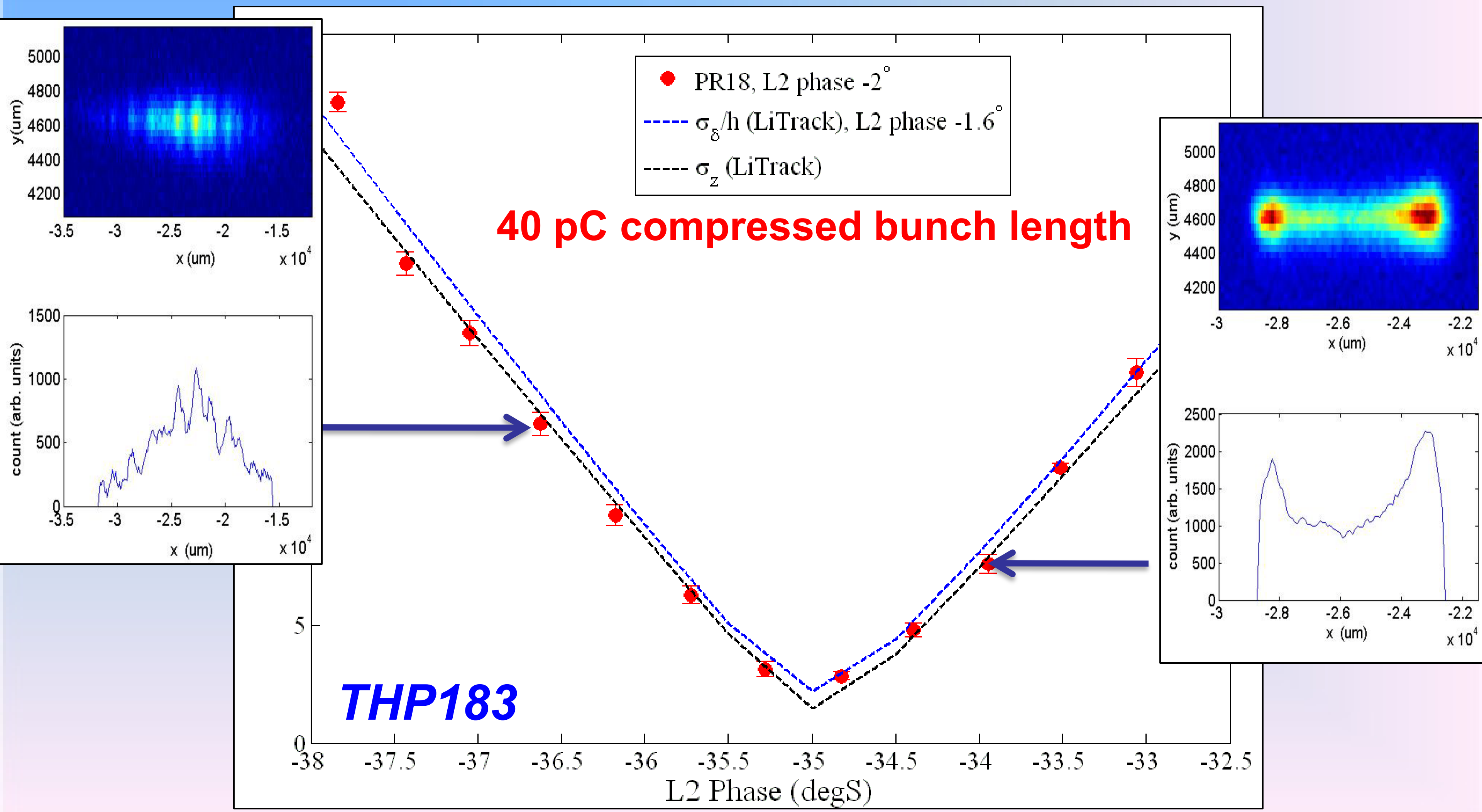
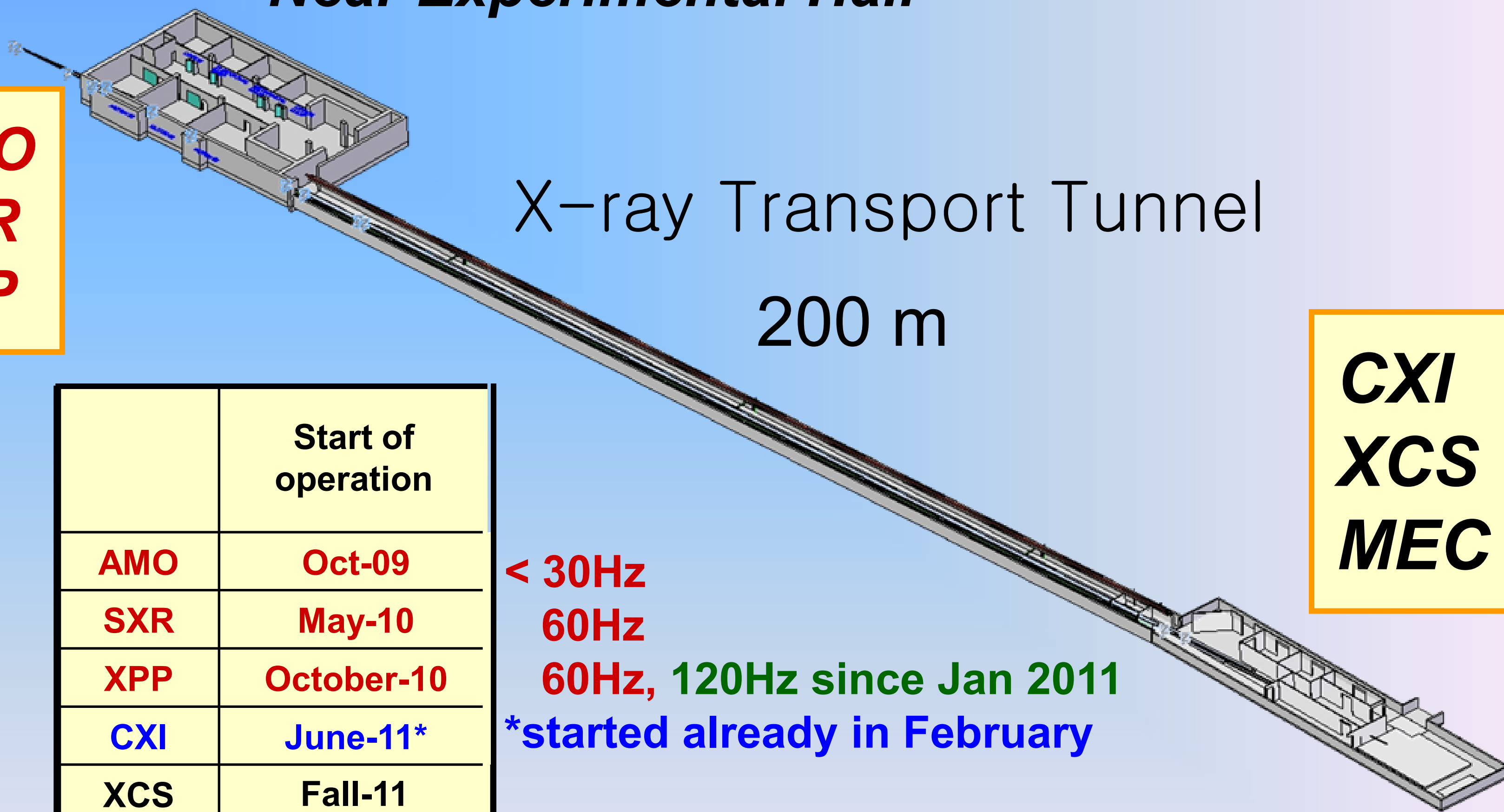


Experimental Halls and Operations Schedules



	Start of operation
AMO	Oct-09
SXR	May-10
XPP	October-10
CXI	June-11*
XCS	Fall-11
MEC	Fall-11

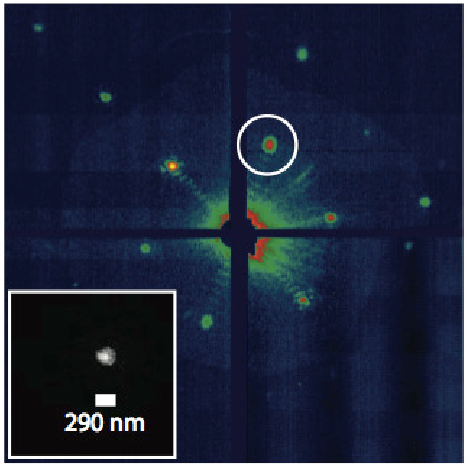
< 30Hz
60Hz
60Hz, 120Hz since Jan 2011
*started already in February

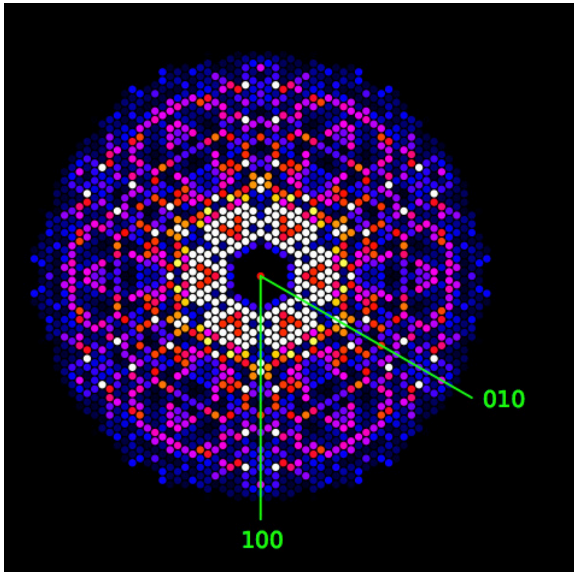
Many high impact publications in Nature, PRL…

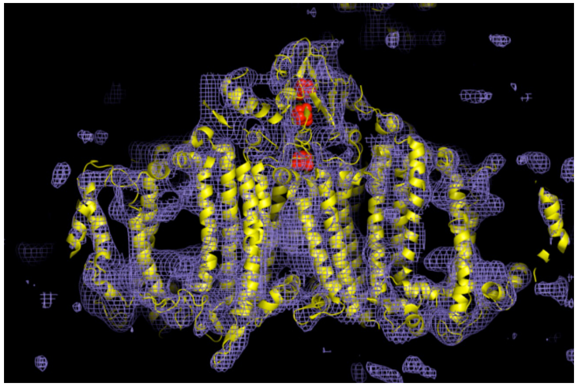
U. Bergmann

Femtosecond x-ray nanocrystallography overcomes limitations of radiation damage

A new paradigm opens up macromolecular structure determination to systems too small or radiation sensitive for synchrotron studies, and may save years of effort in crystallization trials







Single-shot diffraction patterns are recorded with 70 fs pulses. Coherent diffraction shows the crystal size is sub-micron (top left) and that the crystal has a perfect lattice. Individual shots are oriented in 3D and combined to build up the full information content of the underlying macromolecule (top right). This first demonstration was carried out at 2 keV photon energy, limiting the resolution to about 9 Å. (This will be improved with the dedicated CXI instrument.) The quality of the data are demonstrated by carrying out molecular replacement refinement (right). Structural details such as helices can be observed.

- The ultrafast LCLS x-ray pulses allow us to record "diffraction before destruction" where information is obtained before the onset of structural damage.
- Diffraction can be measured from sub-micron crystals containing less than a thousand molecules.
- Demonstrated using Photosystem I, a membrane protein, key to photosynthesis, that is extremely difficult to grow into large crystals.
- 30 single-crystal patterns per second were recorded from a liquid stream carrying a suspension of nanocrystals. 15,000 of these were indexed and combined into a full diffraction pattern which was analyzed with standard tools.
- Data are collected at room temperature. No cryogenic cooling or stabilization required.

Outline

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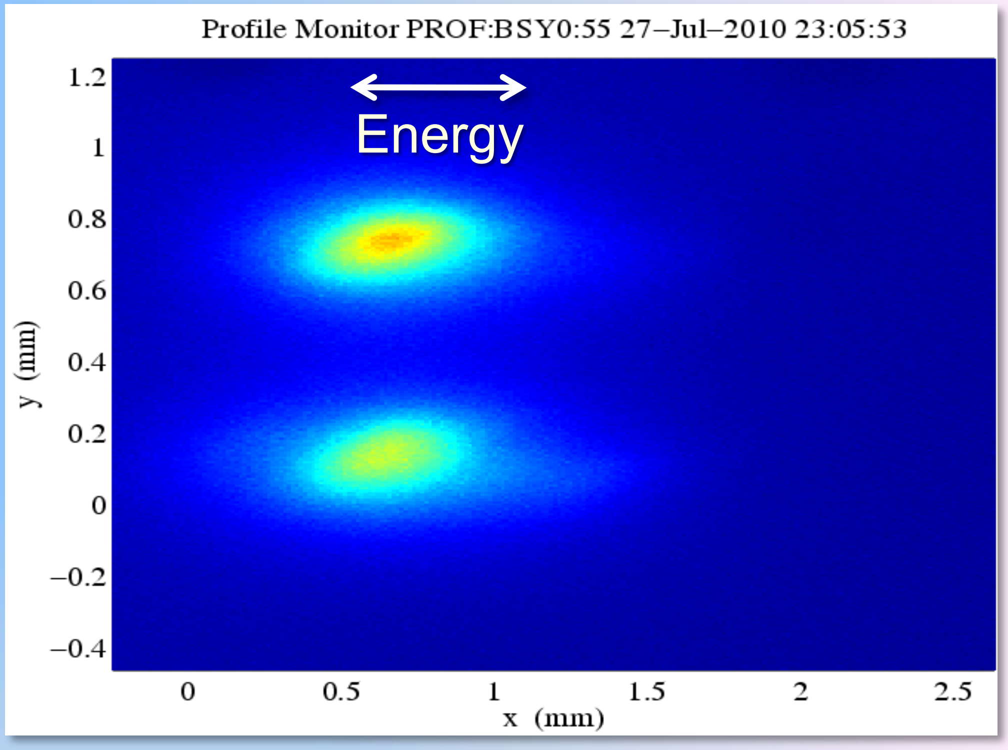
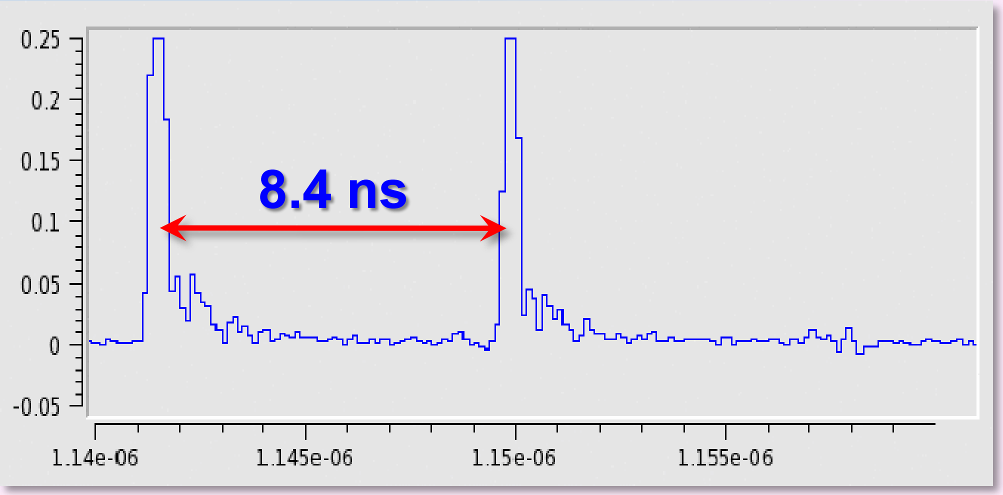
Two FEL pulses demonstrated at *LCLS* (8.4 ns)

- Two electron bunches in one RF pulse observed on screen and separated vertically using an RF deflector

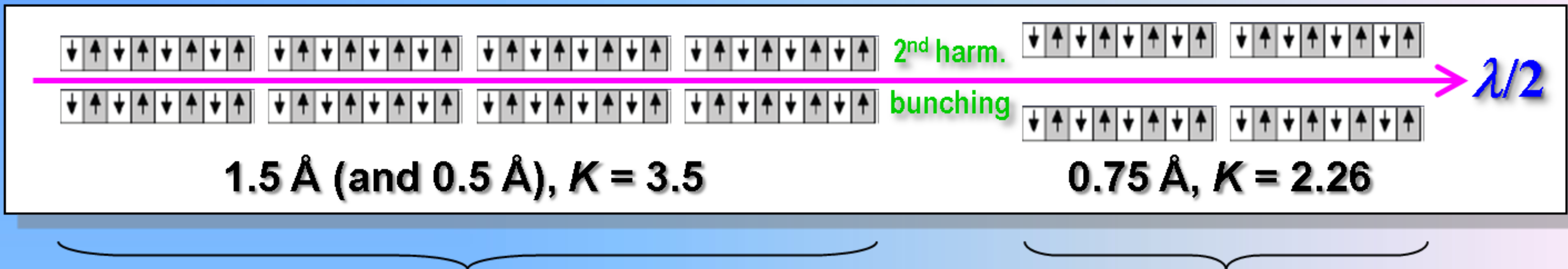


- Two FEL photon beams also observed (2 keV)



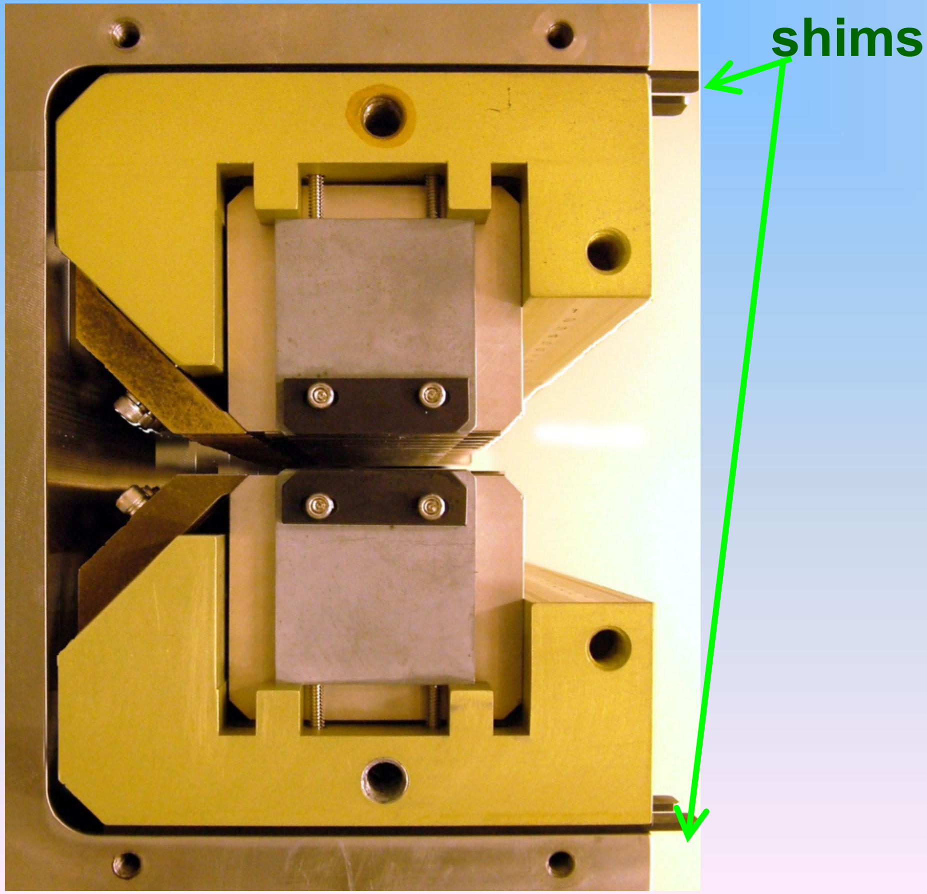
F.-J. Decker, FEL2010

Second Harmonic Afterburner (SHAB)



existing *LCLS* undulator

2nd harmonic after-burner



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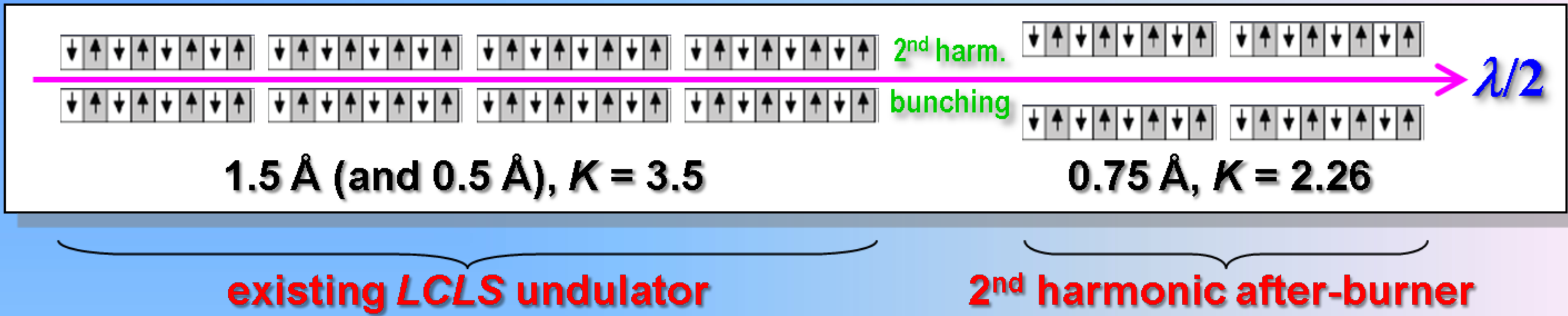

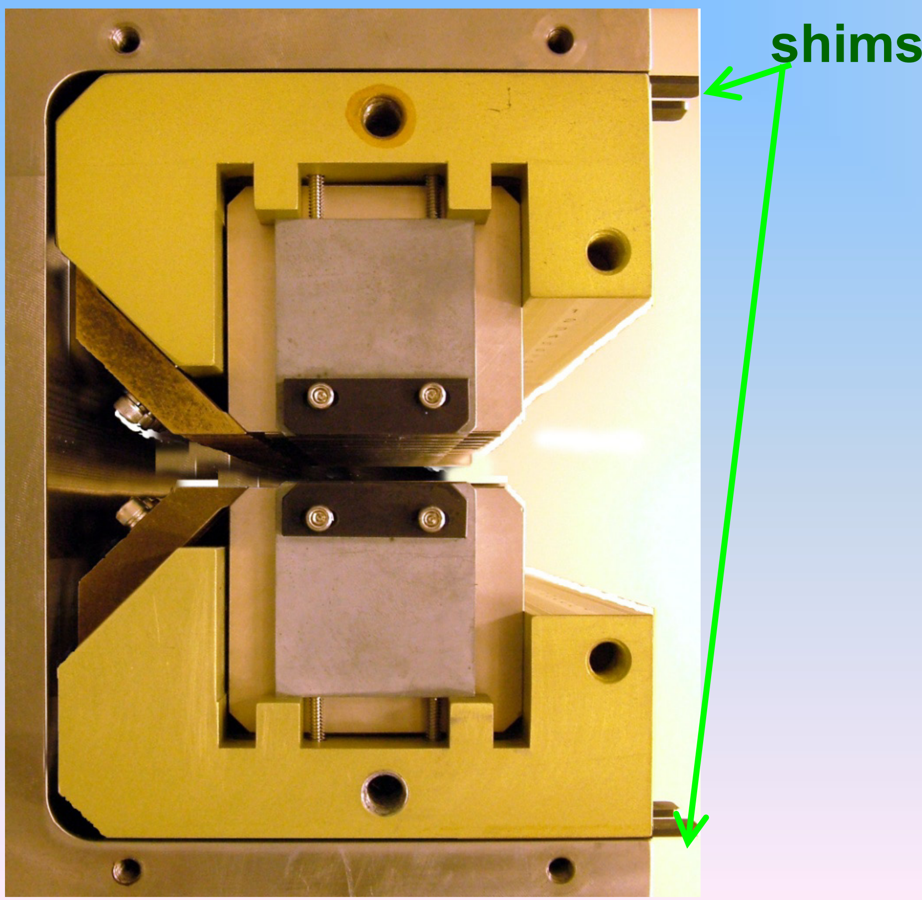

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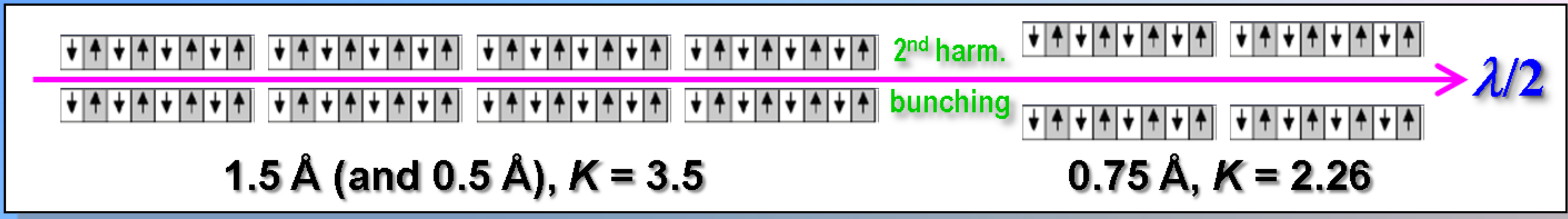

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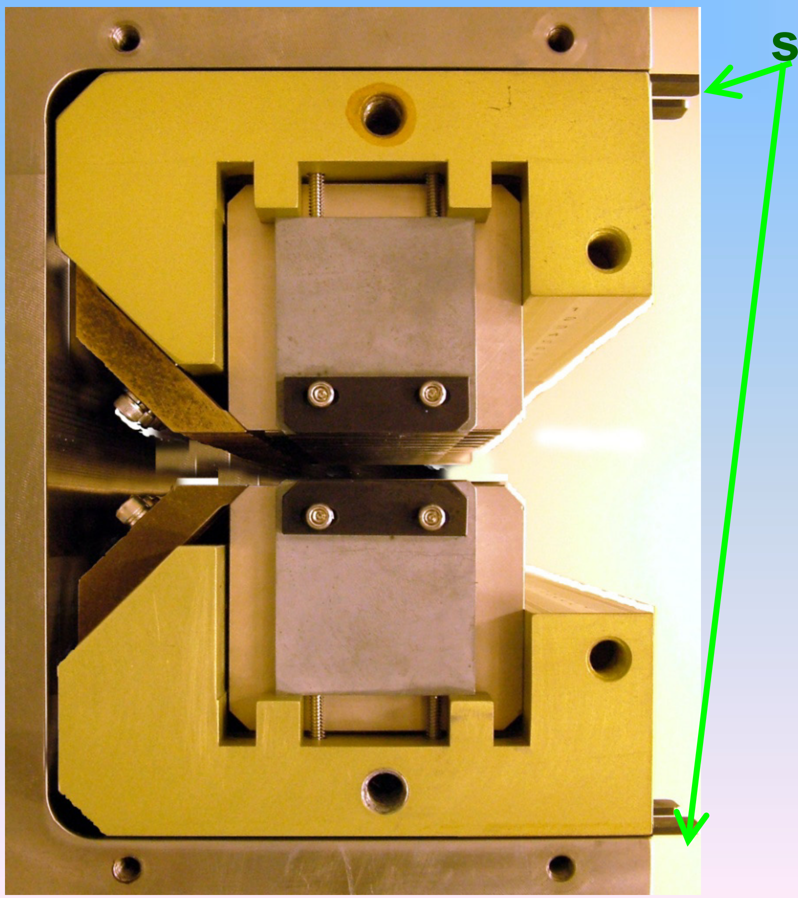

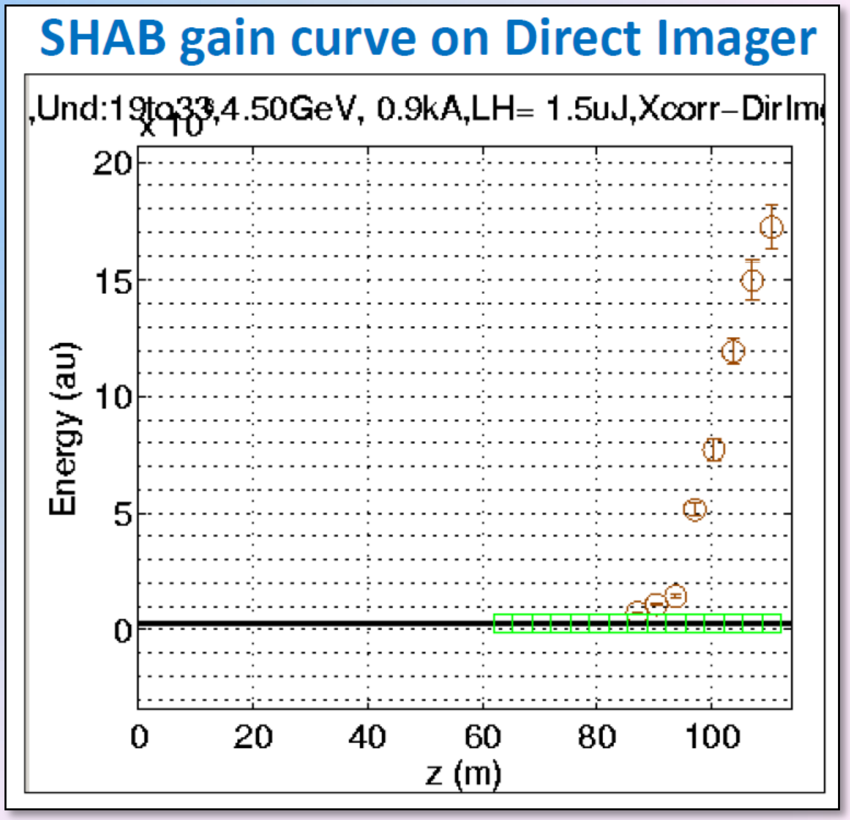

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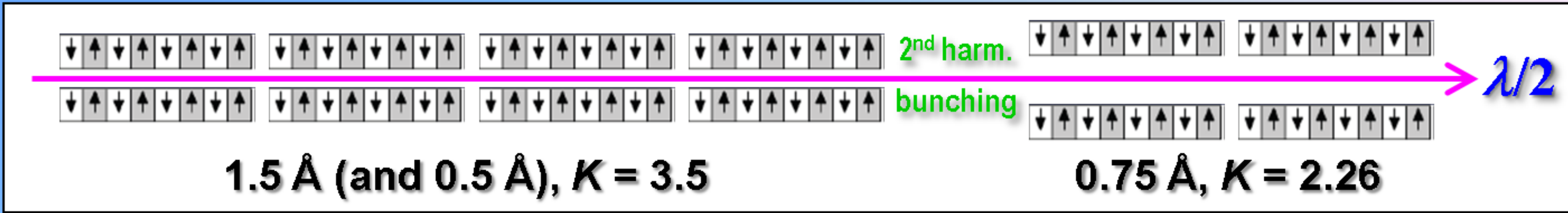

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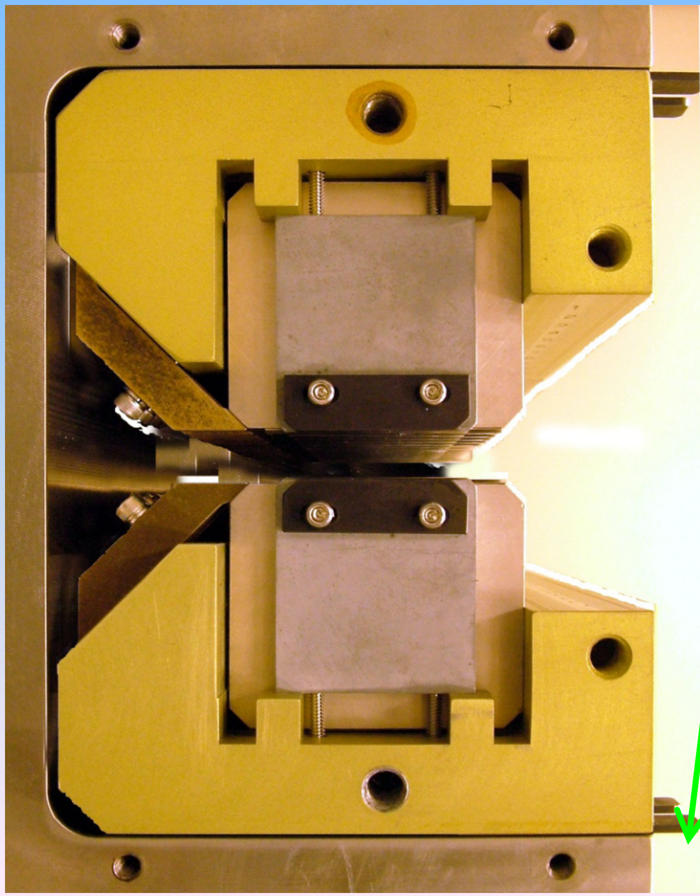
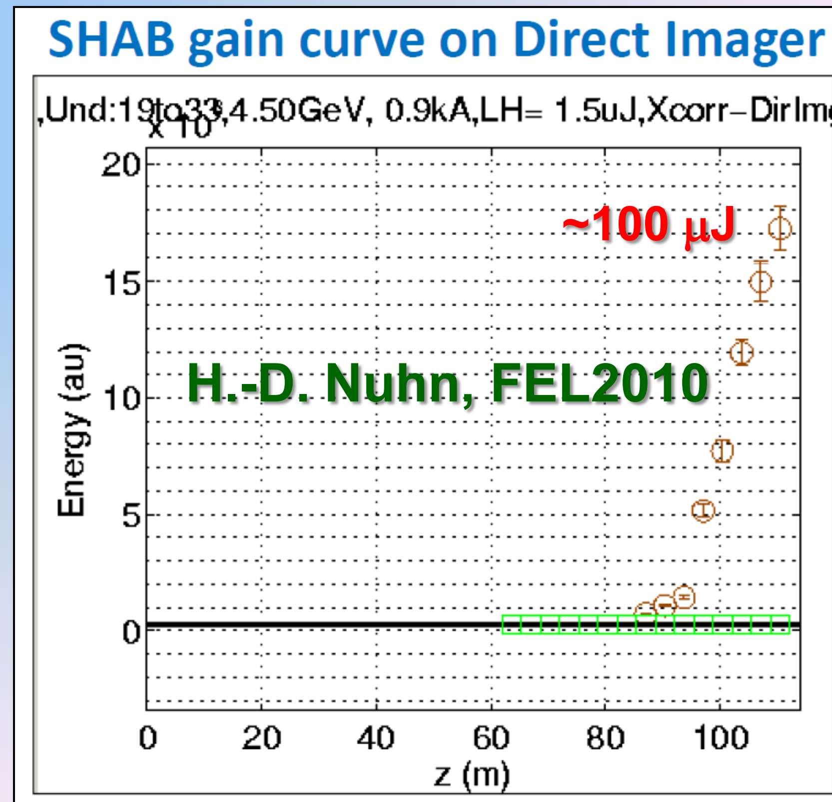


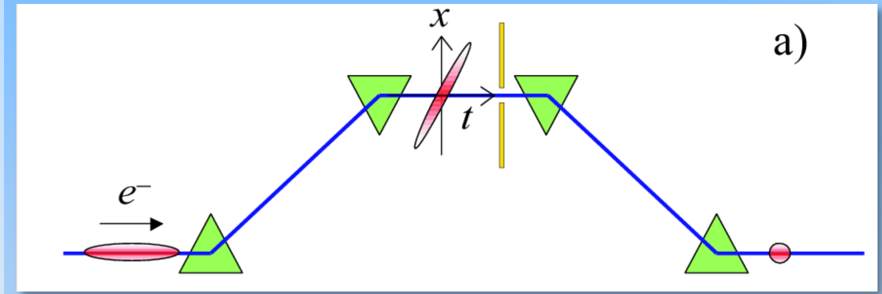
shims

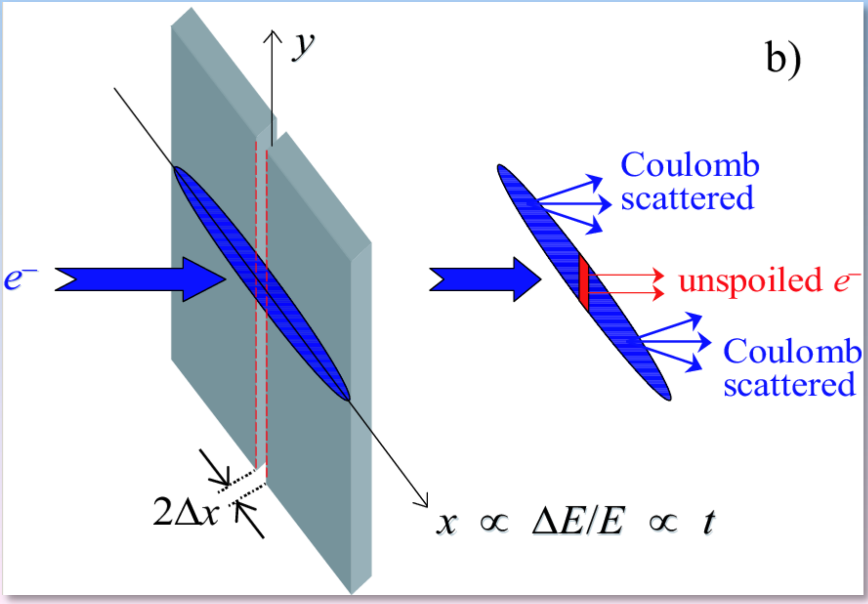


5 SHAB's in, 3 more coming soon

X-Ray Pulse Length Control from a Slotted Foil

PRL **92**, 074801 (2004).
P. Emma, M. Cornacchia, K. Bane, Z. Huang, H. Schlarb (DESY), G. Stupakov, D. Walz





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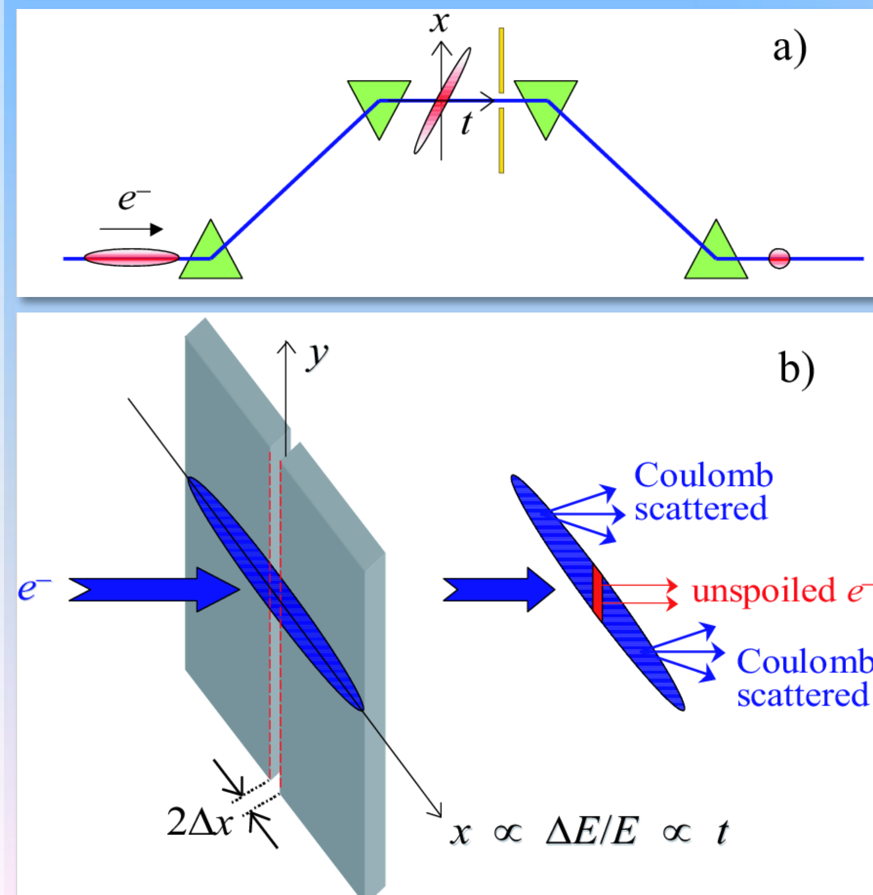

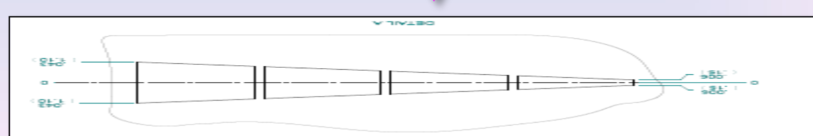

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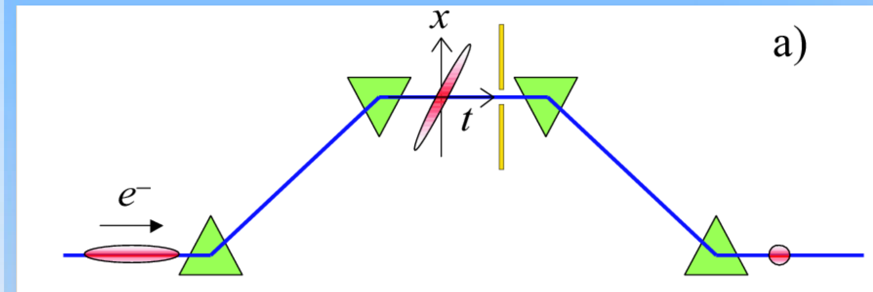
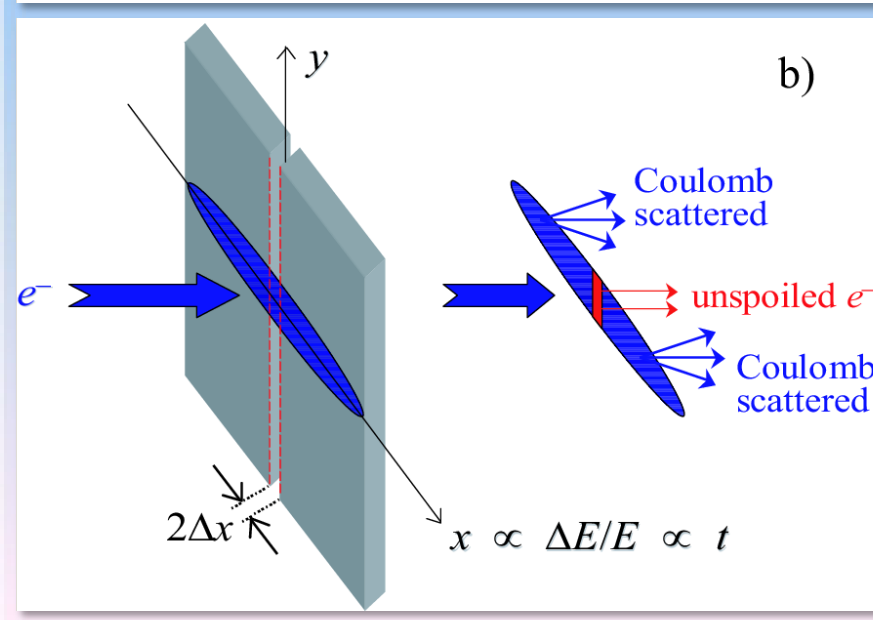
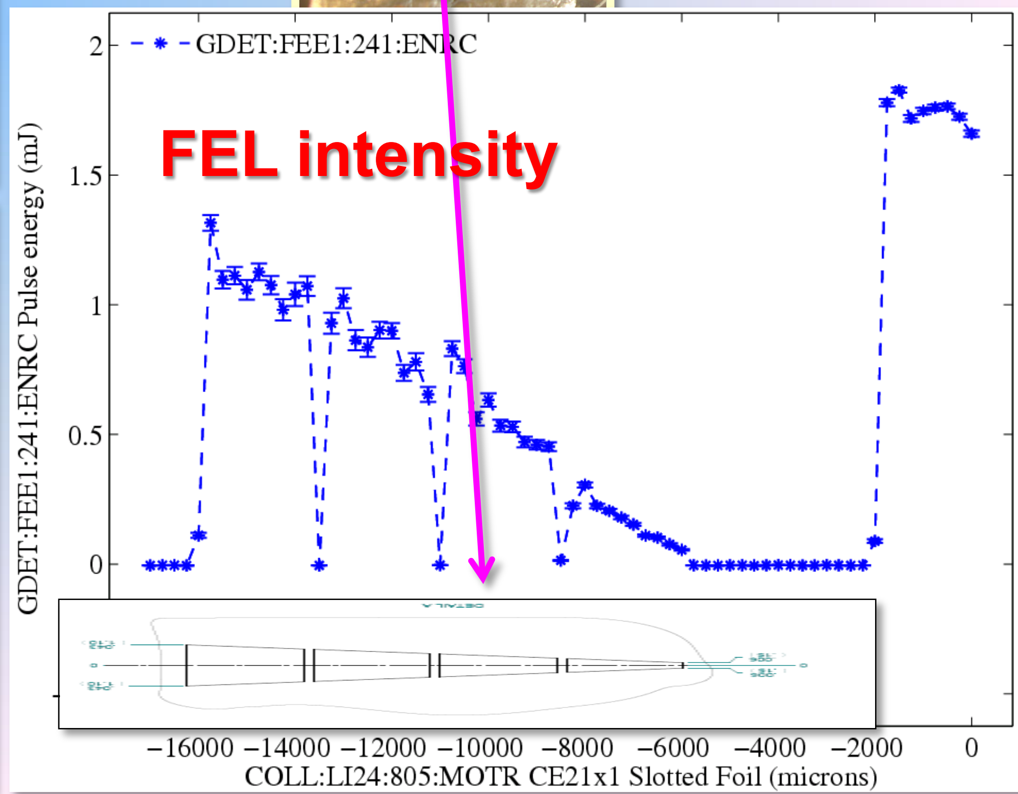
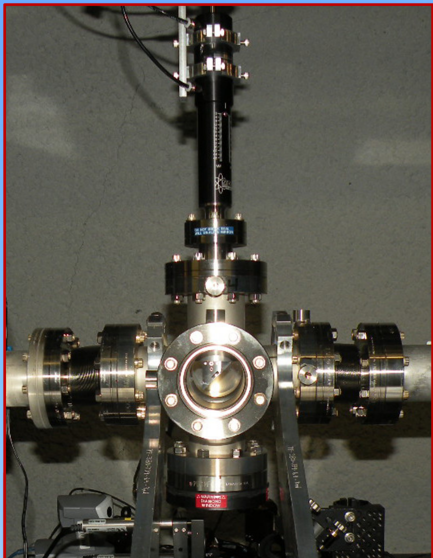




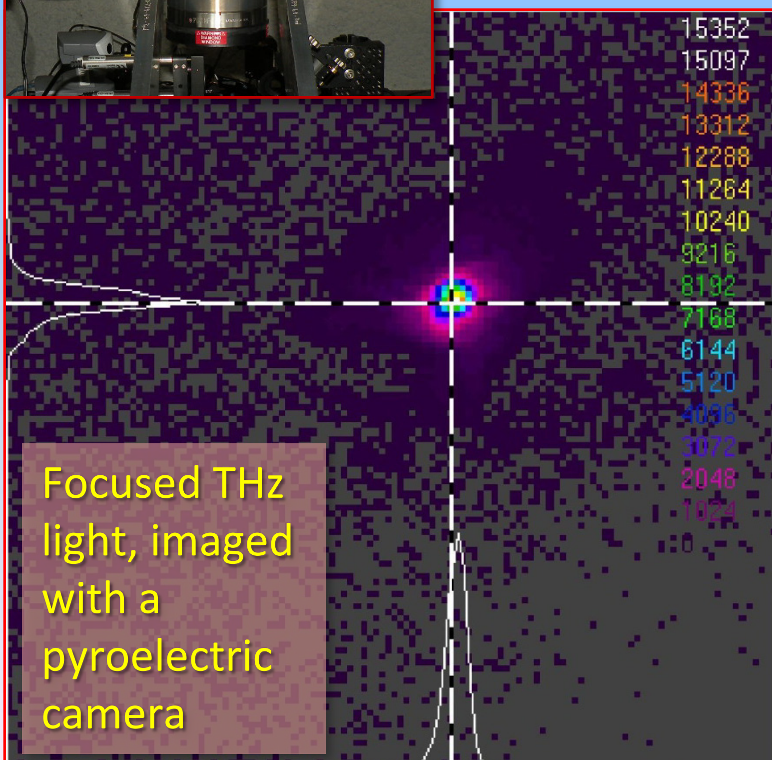


Strong-field, fs THz extracted

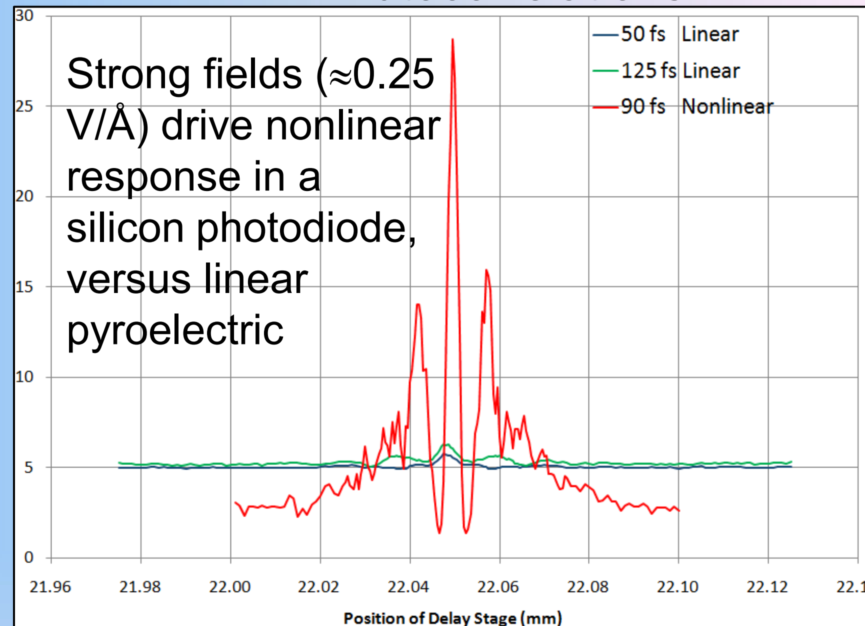


Piston inserts a 2-µm Be foil. THz light exits downward through a diamond window.

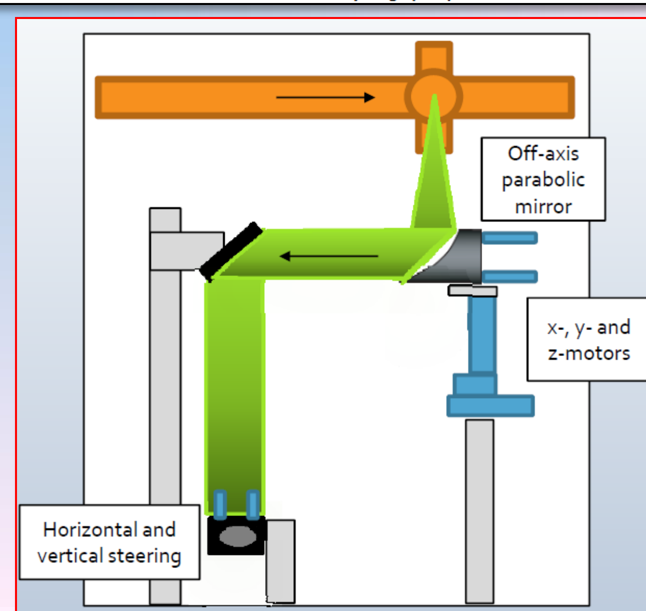
A. Fisher et al.



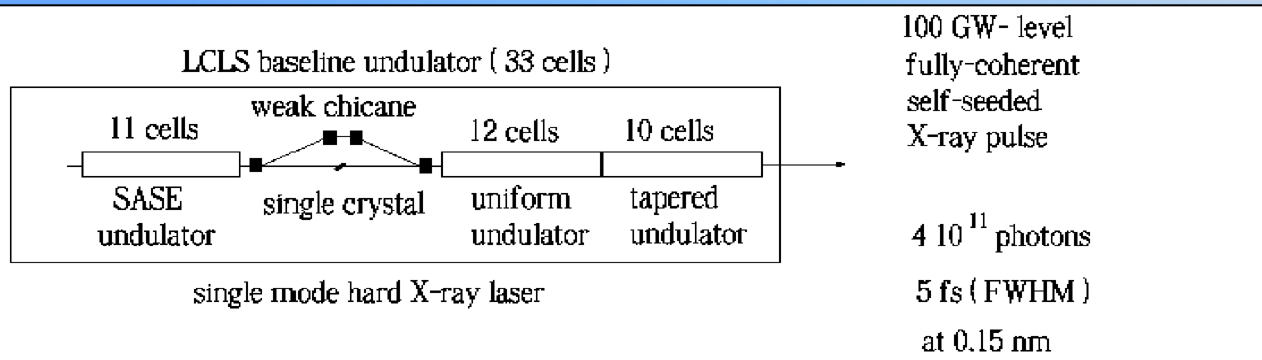
THz Autocorrelations



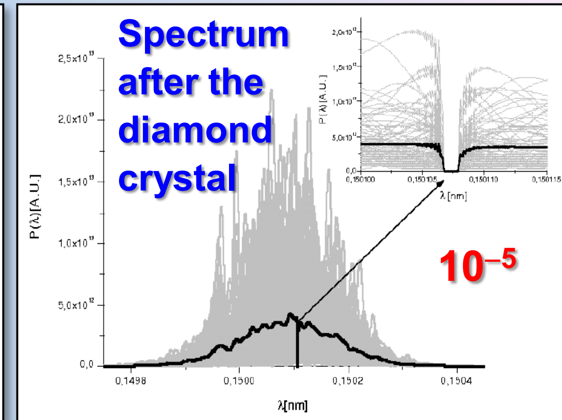
Collection & collimation

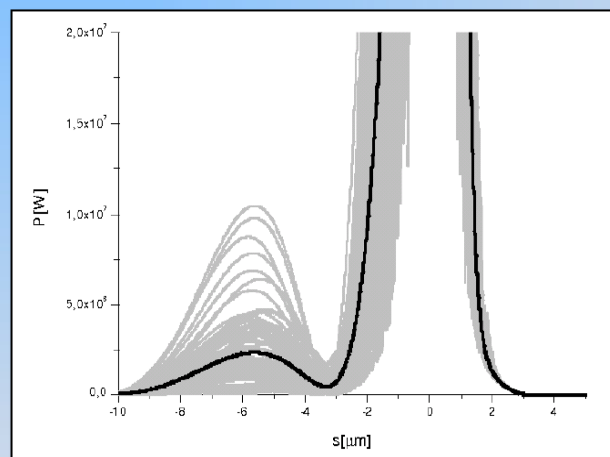


Hard X-ray Self-Seeding @ LCLS

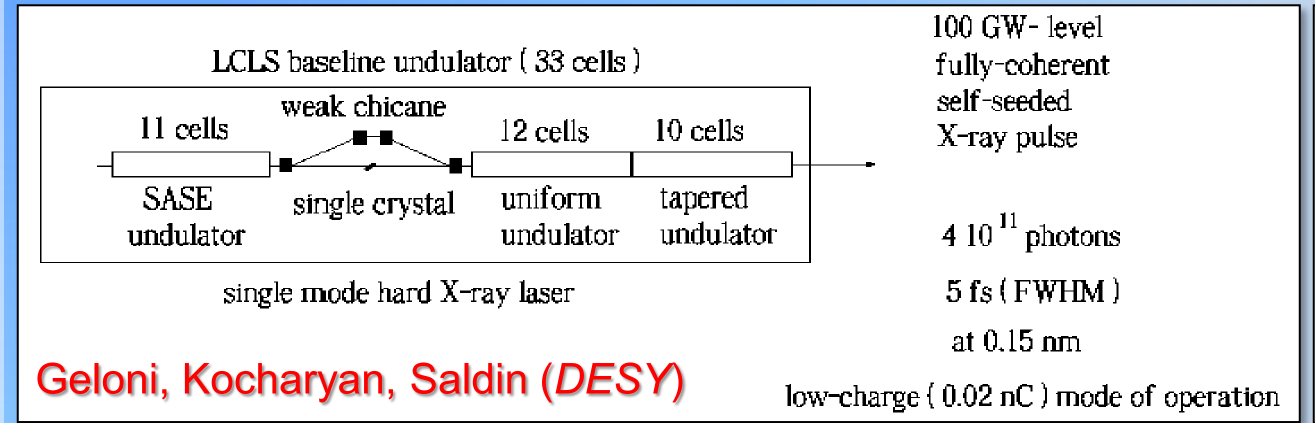


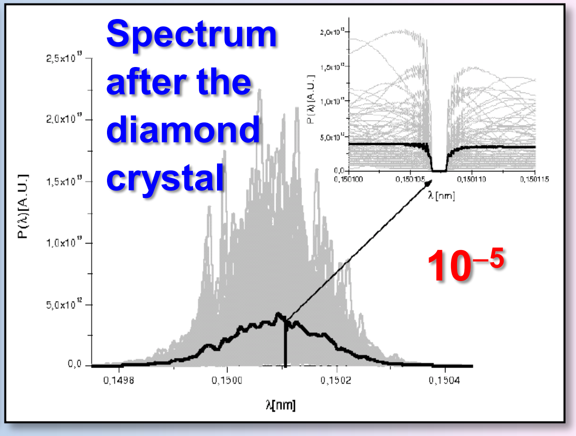
Geloni, Kocharyan, Saldin (*DESY*)

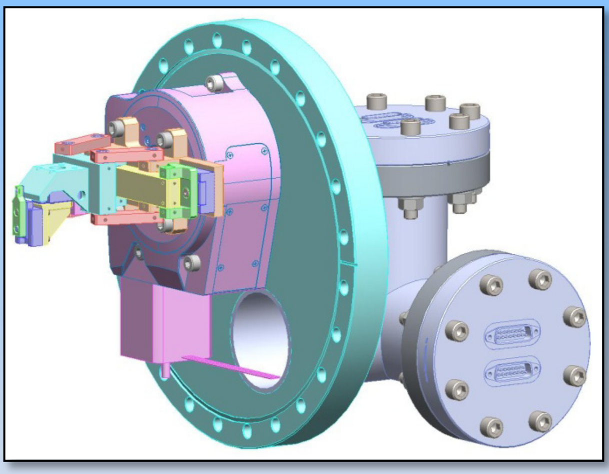


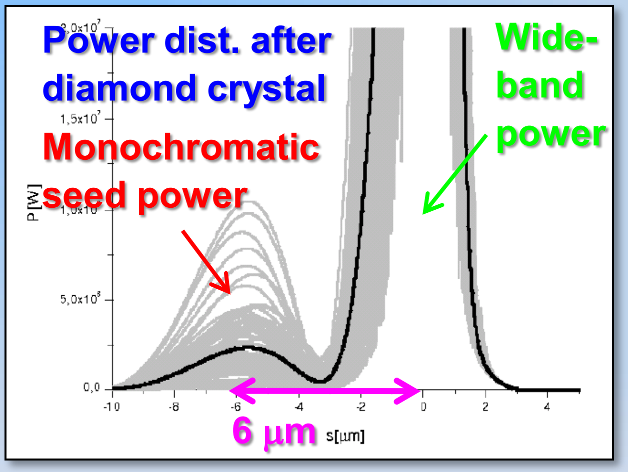


Hard X-ray Self-Seeding @ LCLS



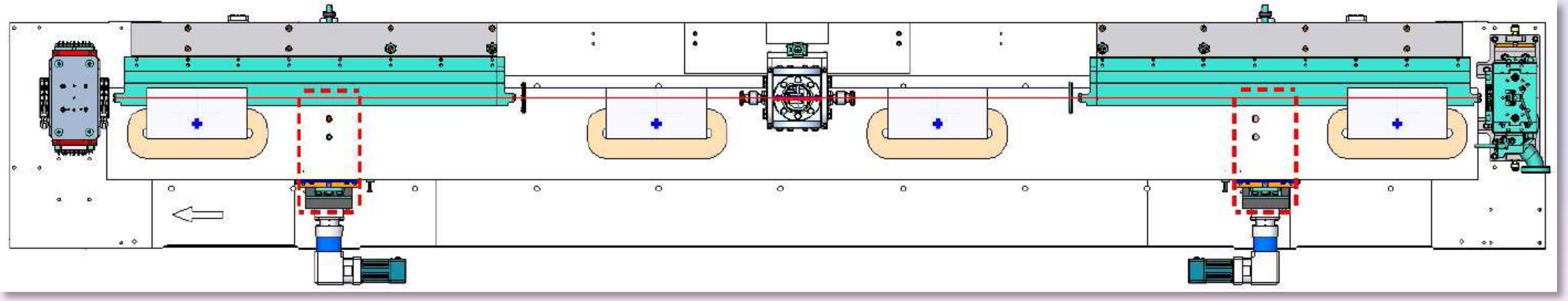






Self-seeding of 1-µm e^{-} pulse at 1.5 Å yields 10^{-4} BW narrow band

P. Emma (SLAC)
A. Zholents (ANL)



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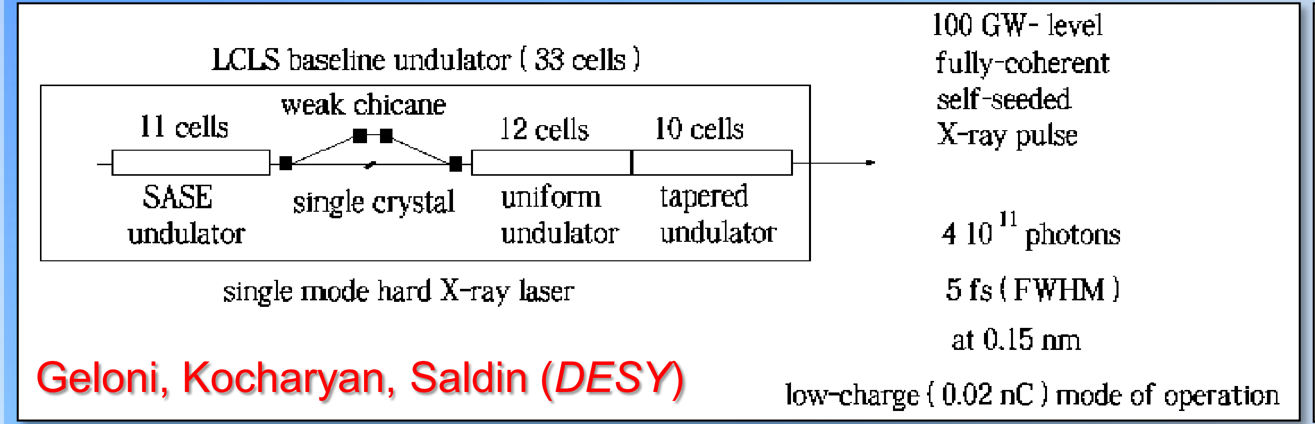

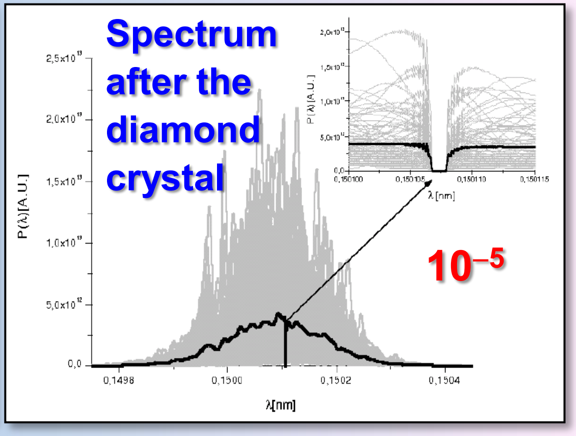

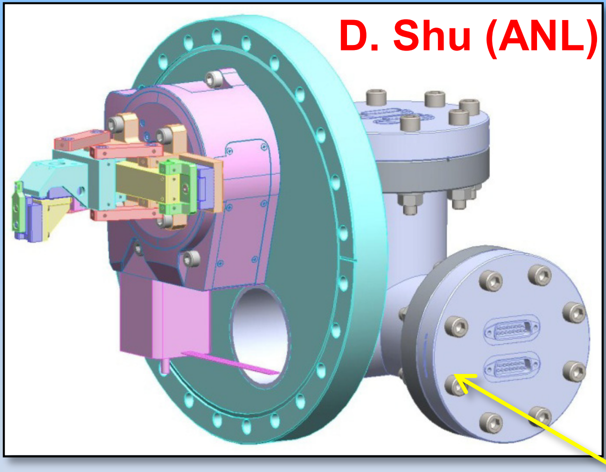

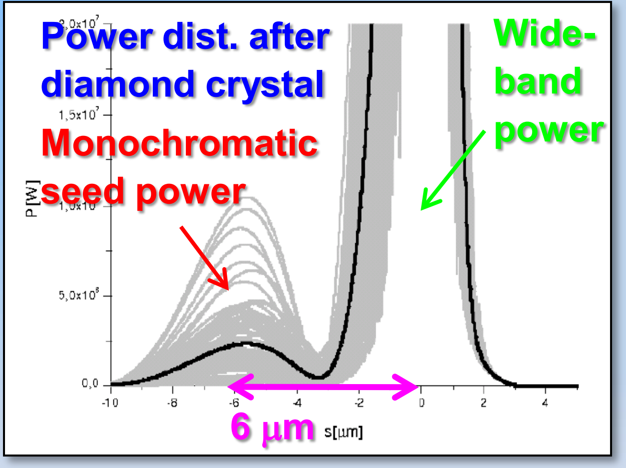

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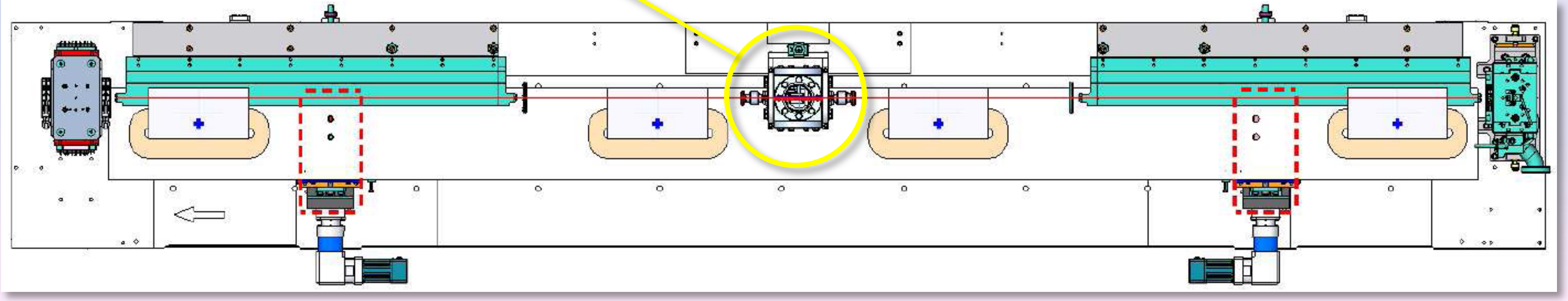
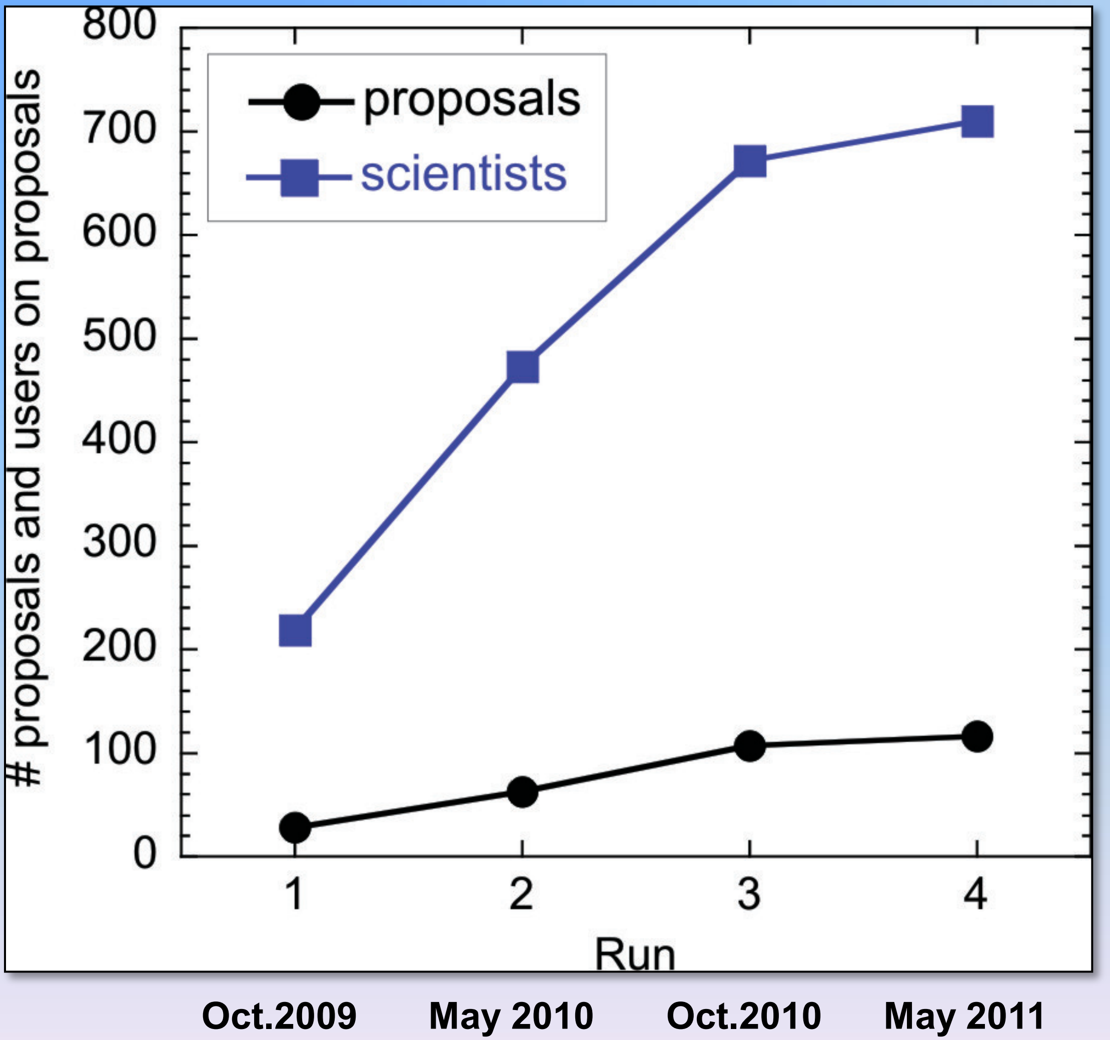


Outline

- Commissioning highlights
- Operation and user experience
- Near term upgrade
- LCLS-II and FEL R&D

LCLS has experienced rapid user growth that is now limited by capacity



314 proposals submitted to date (through 2010)

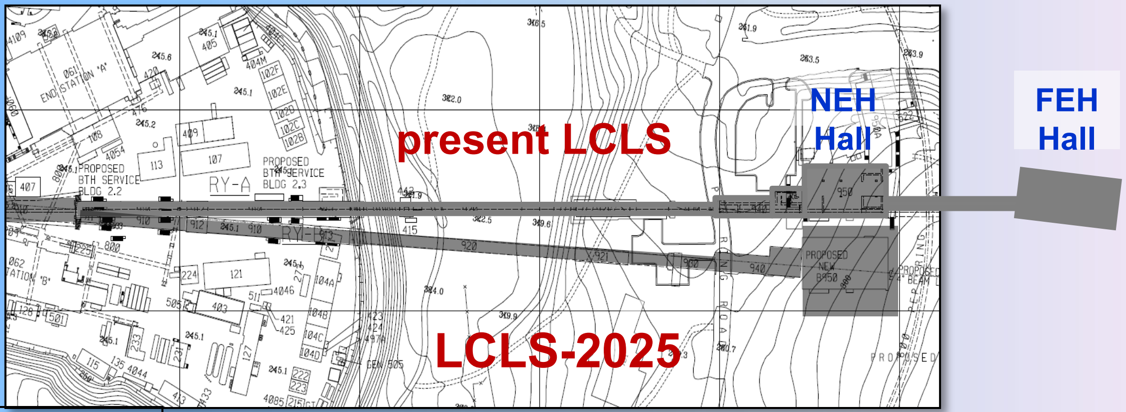
1094 unique scientists from 25 countries
listed as collaborators
on proposals submitted Sept 2008-June 2010

359 on-site users worked at LCLS on scheduled proposals in FY2010

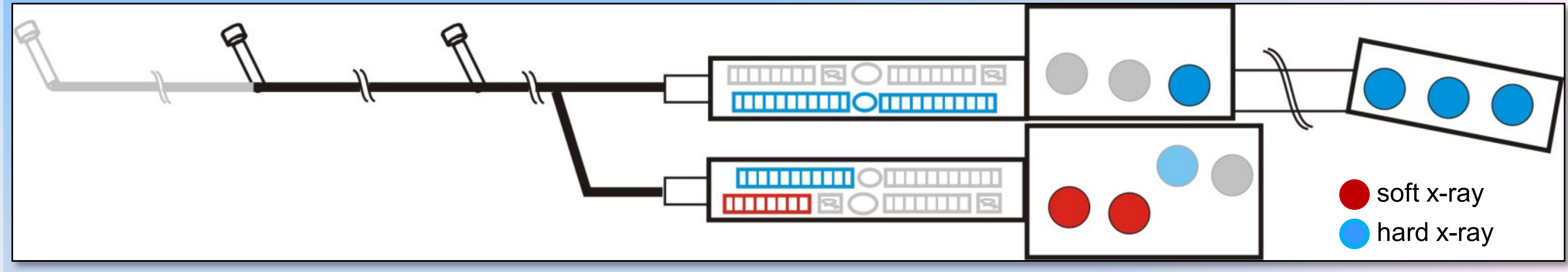
one in four proposals is approved due to capacity limits

LCLS-II as part of a long term Strategy

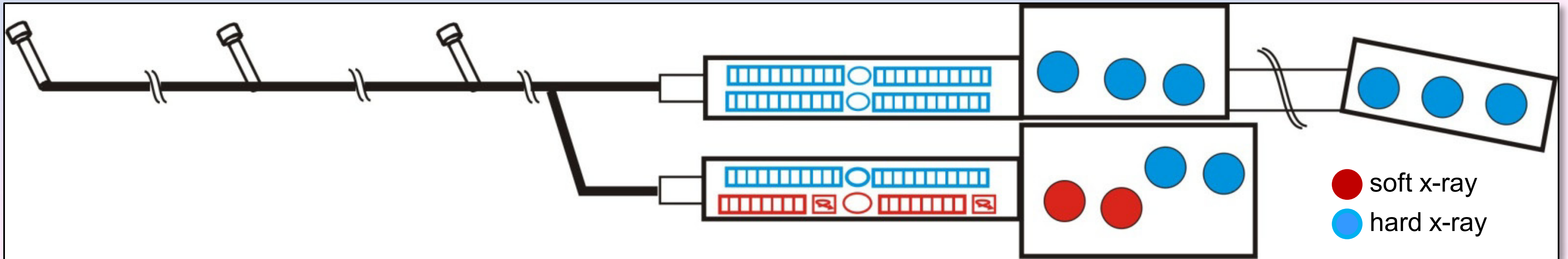
SLAC's vision



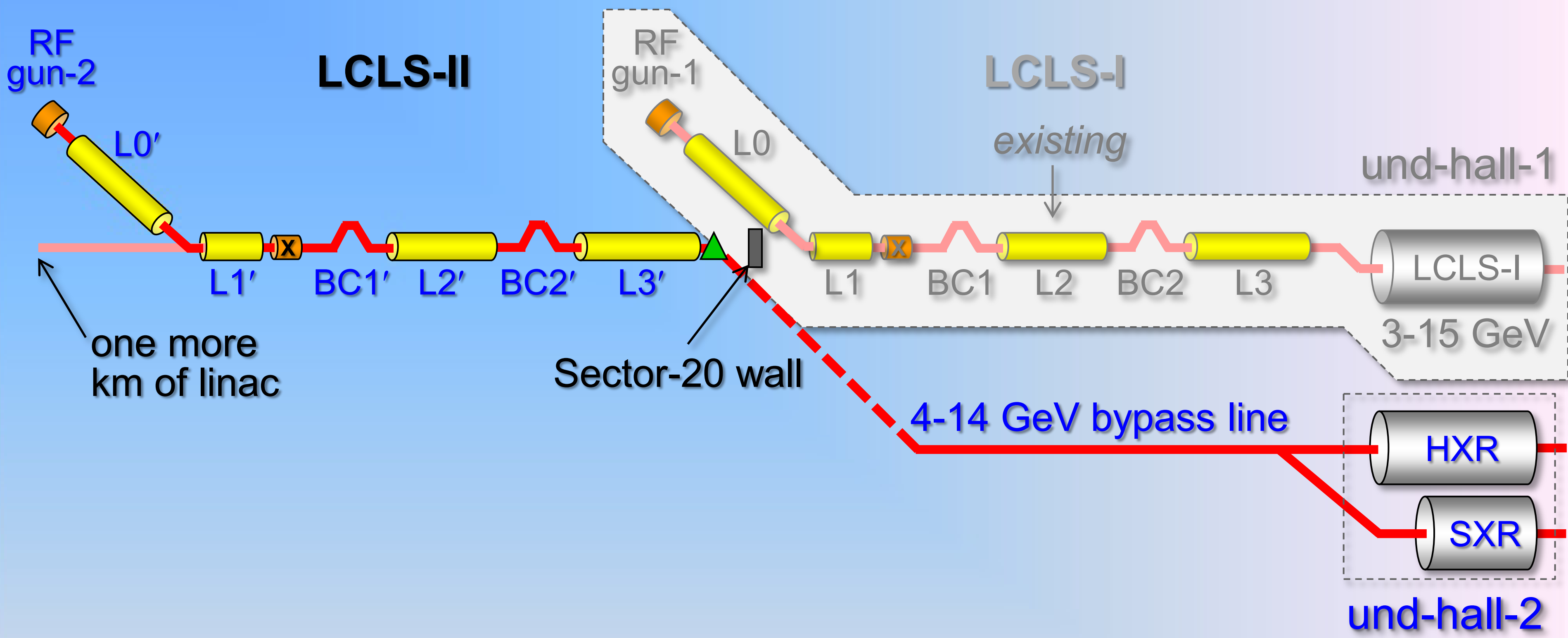
LCLS II (CD-4 2018)



LCLS 2025

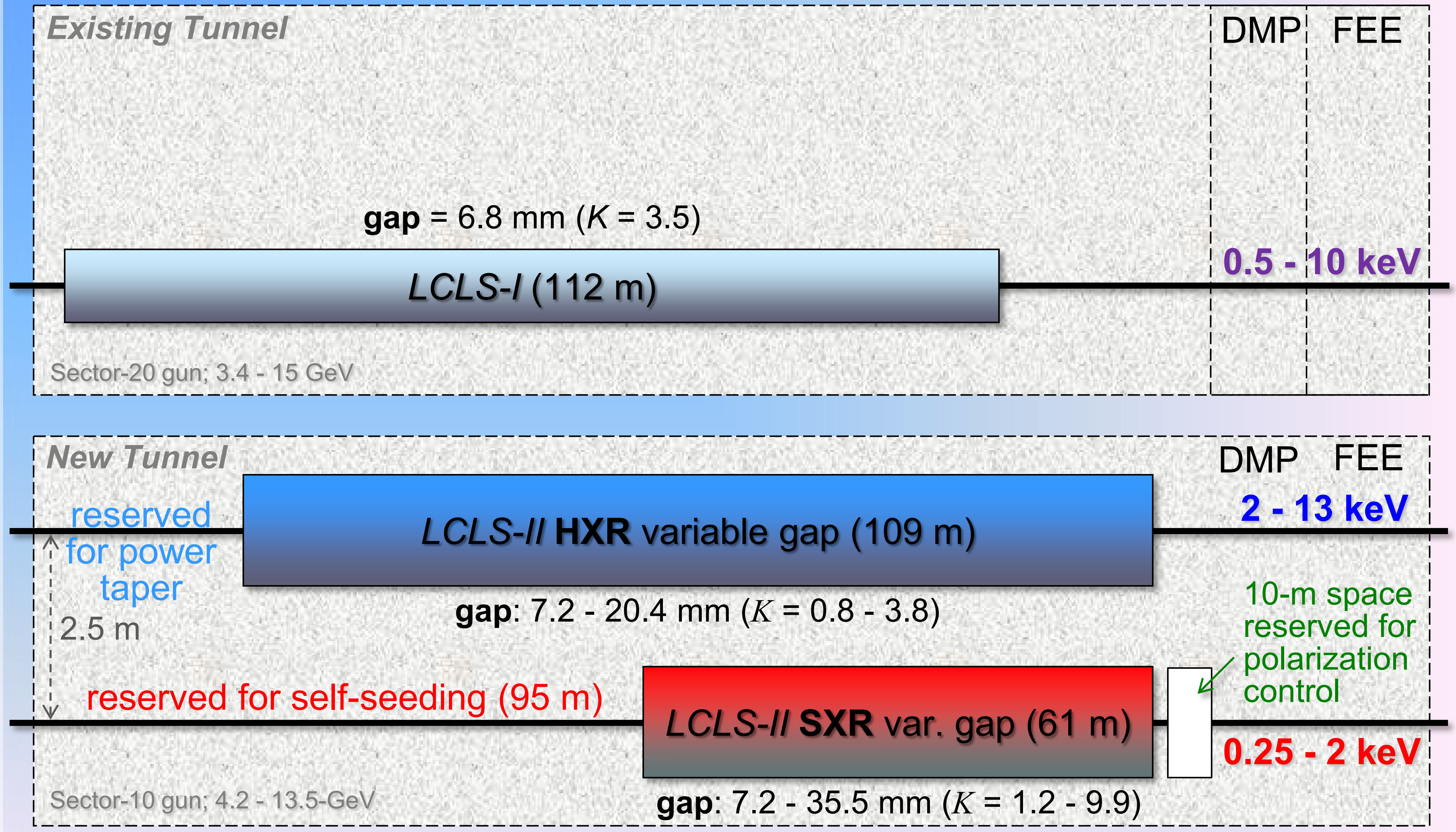


LCLS-II Machine Layout



- Use same injector design at sector-10 (1 km upstream)
- Two new bunch compressors and 4-14 GeV linac (~1 km)
- 1200-m long bypass (old PEP-II line) goes around *LCLS-I*
- Two new undulators (HXR & SXR) in new tunnel
- Baseline is 60 Hz in each undulator (multi-bunch later)

LCLS-II: Hard and Soft X-Ray SASE



FEL R&D

- Polarization control
- THz pump and X-ray probe
- fs and (sub-fs) x-rays and timing
- Self seeding (both hard and soft x-rays)
- Echo seeding (*TUODS3, D. Xiang*)
- Multi bunches
- TW-FEL

Conclusions

- LCLS is a revolutionary x-ray facility and its performance has exceeded expectations.

- Rapid progress on capabilities continues and is immediately utilized by users.

- LCLS-II builds on LCLS success and strong user demand.

- A vibrant R&D program is a key element of the LCLS future.

Thank you!